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WEEKLY 7 December 2024

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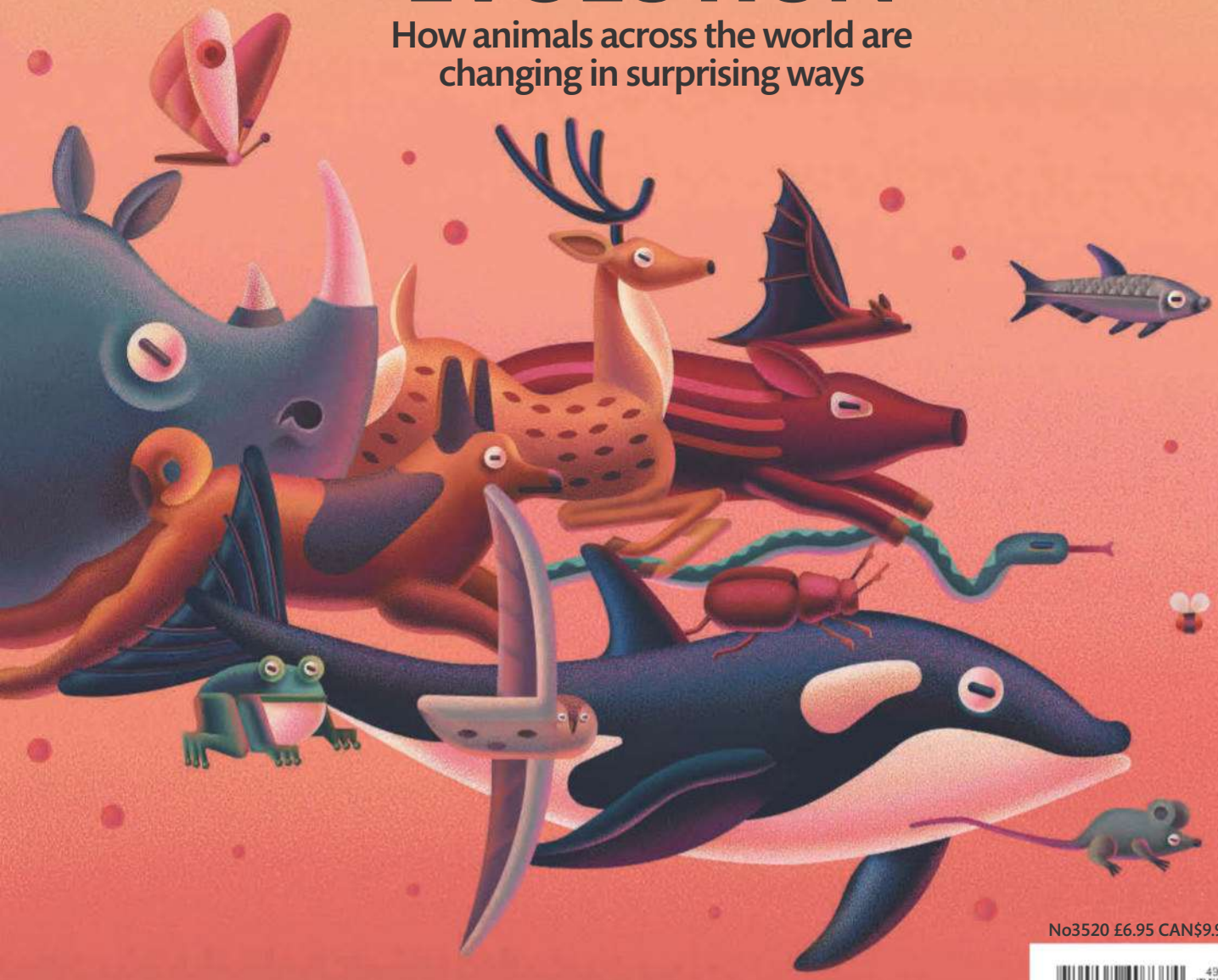

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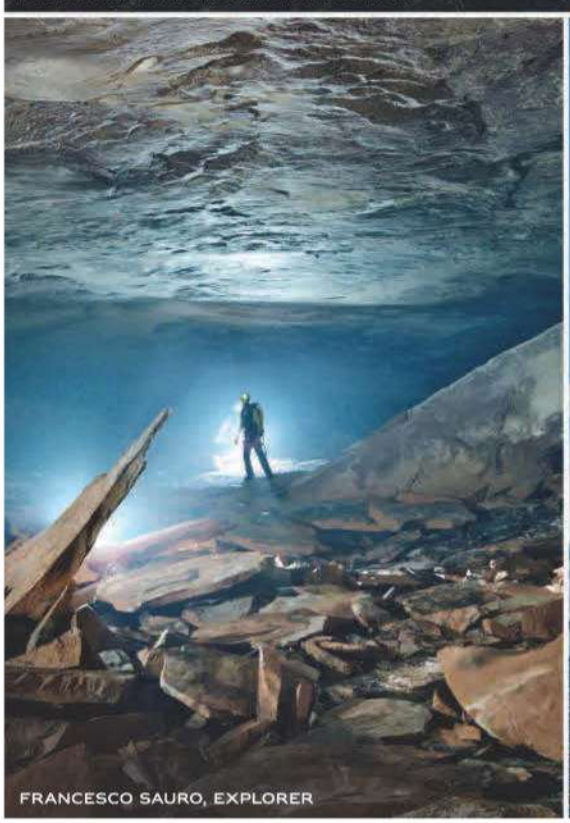

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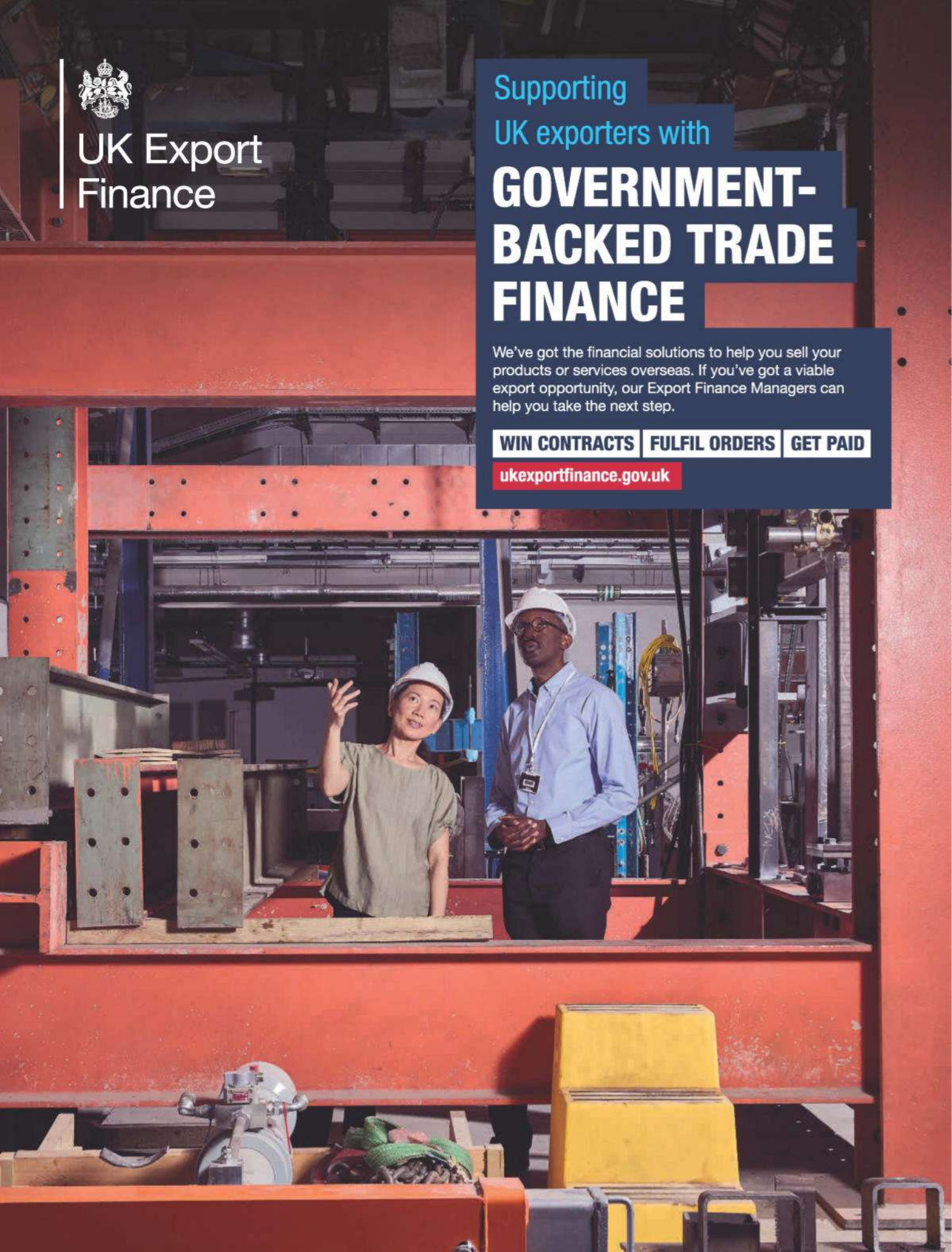
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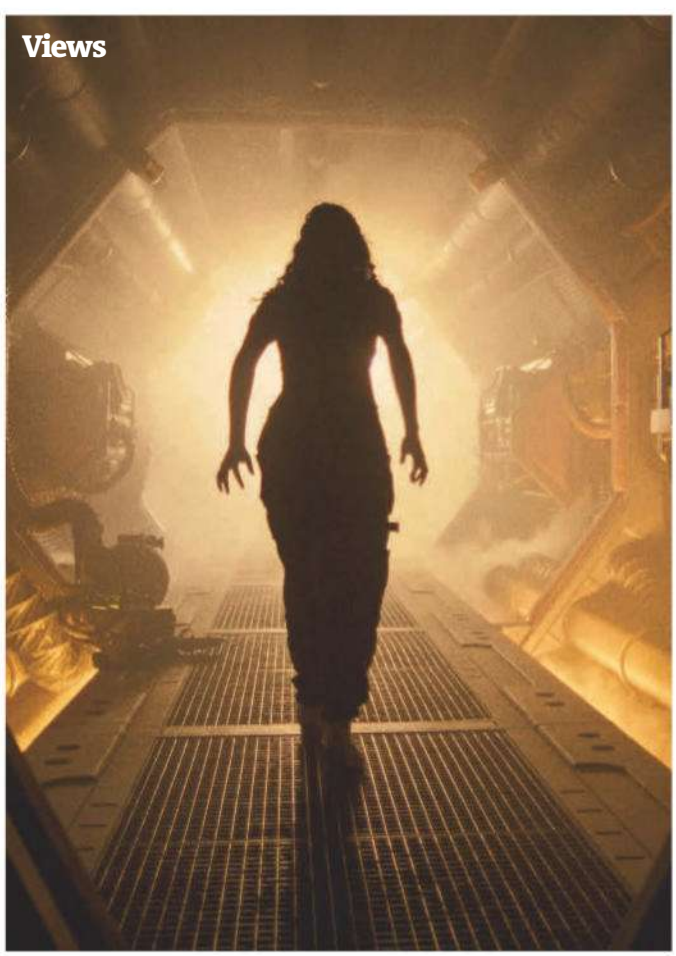

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Mysteries of matter

Ever since the model of the atom was devised a century ago, scientists have carried out ever-grander experiments with gigantic, atom-smashing particle accelerators to probe deeper into what these particles are made of. But our best theory, the standard model, isn't quite complete. Join six leading experts to find out everything we know about particles – and what puzzles remain – on 18 January at London's Congress Centre.

newscientist.com/events

Tour

The world capital of astronomy: Chile

Stargaze beneath some of the clearest skies on Earth. With 70 per cent of the world's telescopes, Chile truly is the global capital of astronomy. Join astronomer Martin Griffiths as you visit some of the world's most advanced observatories, including Vera C. Rubin. This 13-day tour starts on 27 March and costs £10,999.

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MASSIMO DALLAGLIO/ALAMY

Large Hadron Collider Particle smashers reveal fundamental reality

JARED LAZARUS/DUKE UNIVERSITY

Jump for joy Building better relationships between dogs and people

Podcast

Watch on YouTube

Our long-running weekly podcast is now available on our YouTube channel, where you can watch our hosts and reporters digest the latest big science news. This week, hosts Timothy Revell and Penny Sarchet discuss the possibility of bird flu passing between people and give a rundown of the best science books of 2024.

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Video

Good dog

Most dogs aren't bred to feel at ease in our homes, but scientists studying puppy cognition have found ways you can help yours adapt to life inside. Researchers have created a "puppy kindergarten" where they are studying dogs' cognitive developmental milestones and devising new methods that can help owners to train their pets.

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Newsletter

Health Check

Losing weight can be incredibly frustrating. After months of lifestyle changes, people with obesity may experience rebound weight gain. Often people point to simple causes, such as it being hard to stick to a low-calorie diet, for example. But it is now clear that it is about much more than willpower.

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Podcast

"Bird flu has been threatening to cross over into humans for some time now"

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Evolution evolves

But that doesn't mean our central theory of life on Earth is wrong

DARWINIAN thinking has been challenged many times, starting with co-discoverer of natural selection Alfred Russel Wallace, who disagreed with some aspects of Charles Darwin's arguments, but was eventually proved wrong on most of them. The US botanist Liberty Hyde Bailey published a paper in 1894 pondering whether the formulation of neo-Darwinism, the mainstream version of evolutionary theory, needed extending (it didn't); in the 1980s the palaeontologist Stephen Jay Gould pursued a similar line.

Evolutionary biologist Kevin Lala also has doubts about what he calls traditional Darwinian thinking (see page 26). Some say this is a straw man argument, as it takes issue with old-fashioned ideas about evolutionary biology, whereas modern thinking is broad enough to encompass all the new aspects we are learning about, from developmental biology, cultural evolution and symbiosis, when two different species live together intimately.

Over the years, the theory of evolution by natural selection has itself evolved, absorbing new findings about genes, DNA, population genetics and epigenetics, all of which weren't available in Darwin's time. As we report on page 11, identifying evolutionary drivers is essential if, for example, we are to get ahead of a bird flu pandemic, as well as understanding how species will adapt to climate change. Whether we need to add to the rule book evolutionary biologists already have at their disposal is debatable. There is a danger of allowing a "god of the gaps" argument to creep in, where apparent shortcomings in evolutionary theory are exploited by those who point to non-scientific explanations.

> "Apparent shortcomings create a danger of a 'god of the gaps' argument creeping in"

All theories need to be challenged, and assessing modern evolutionary biology brings to the fore many aspects of life that might not be well appreciated. Darwin's explanation has survived for more than 160 years because it is broadly correct and robust enough to absorb new discoveries. The impact of Lala's approach is therefore not yet clear – but its scrutiny of neglected aspects of life is to be welcomed. ▮

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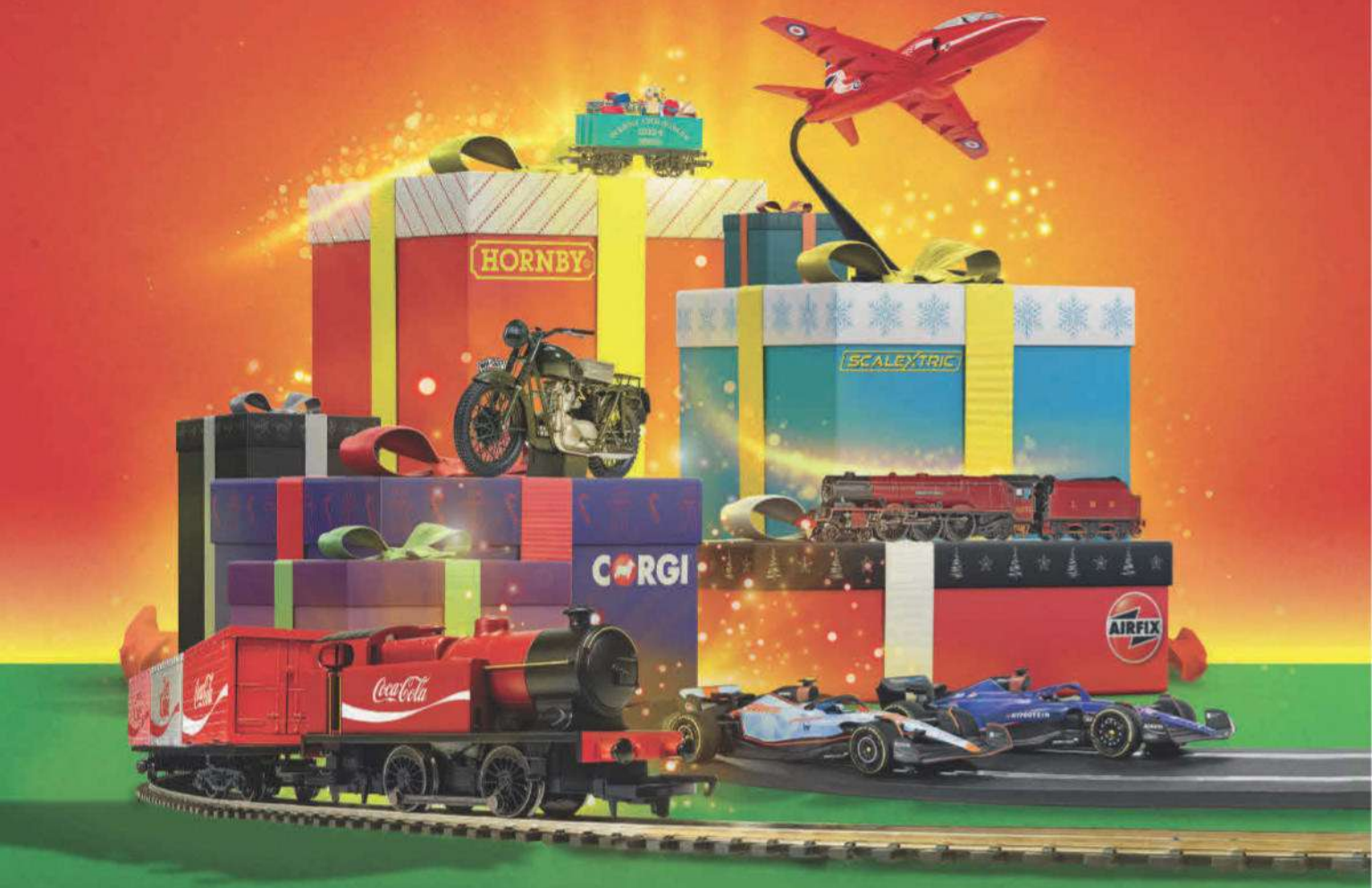

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Fossil faeces reveal how dinosaurs came to rule Earth p15

GUY BELL/SHUTTERSTOCK

Zoology

One of the largest eggs ever laid

Bigger than any dinosaur egg, this cracking object is up for sale at auction house Christie's. Laid by an elephant bird, the egg is 30.5 centimetres tall and equivalent in volume to 150 or so chicken eggs. Endemic to Madagascar, elephant birds (*Aepyornis maximus*) were flightless. They reached 3 metres tall, making them the largest birds to have lived, and went extinct about 1000 years ago.

Climate change

Antarctic ice is at a crisis point

The past two years have seen unprecedented falls in the levels of sea ice around Antarctica. Researchers are now racing to understand the global impact of what could happen next, says **James Woodford**

IF ALL our fear and uncertainty over climate change could be distilled into a single statistic, then arguably it was delivered to an emergency summit on the future of the Antarctic last month.

Nerilie Abram at the Australian National University, Canberra, opened her presentation with a slide headlined "Antarctic sea ice has declined precipitously since 2014, and in July 2023 exceeded a minus 7 sigma event".

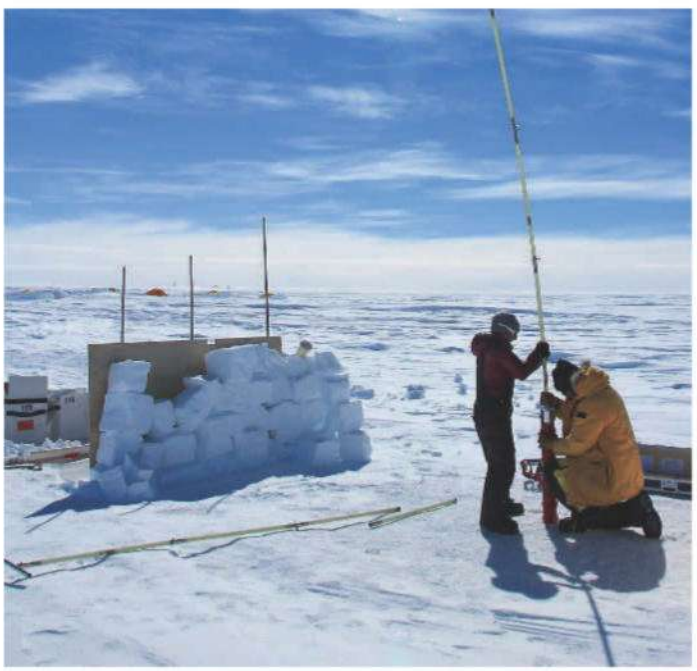
At times, the noise of the 500 researchers who gathered for the Australian Antarctic Research Conference in Tasmania – which ran from 19 to 22 November – was overwhelming, as they tried to make sense of the unprecedented shifts underway at the bottom of the globe. But as Abram's slide sunk in, it was as if the whole room was holding its breath.

Put simply, a minus 7 sigma event, meaning seven standard deviations below the average, should be all but impossible, says Ed Doddridge at the Australian Antarctic Program Partnership, who works with Abram.

It is "actually really hard to convey just how extreme this difference was, how extreme the low sea ice extent was", he says. One way is to liken it to the concept of a one-in-100-year flood, for example. "If you run those sorts of statistics for Antarctic sea ice last year, you get a number somewhere between one in 7.5 million years and one in 700 billion years," says Doddridge.

Given that this event has occurred, something must be wrong with our models. They just aren't able to predict how radically and possibly permanently the Antarctic environment has changed, he says.

The entire Antarctic research community is now scrambling to understand what will happen to the sea ice in the coming years and what the implications will be for everything from local ecosystems to global weather.



NERILIE ABRAM, SAMANTHA SHELLEY

Drilling for ice cores and then transporting them for analysis is helping to reveal the health of the Antarctic

17.16
million square kilometres was the maximum Antarctic sea ice extent in 2024

1.5
metres of sea level rise would happen globally if the Denman glacier melted away

45
years of Arctic ice loss is equivalent to what has been lost in Antarctica in a decade

So just how bad is it? According to the US National Snow and Ice Data Centre, the 7 sigma event was the lowest maximum annual ice extent since records began in 1979. This year was the second lowest, with Antarctic sea ice "stalling out" at 17.16 million square kilometres, or just 200,000 square kilometres more than last year.

Remarkably, that is 1.55 million square kilometres below the expected average extent. In other words, in the past two years an area of ice nearly 6.5 times the size of the UK has disappeared. Another way to imagine it is that the ring of sea ice that forms every winter around the entire Antarctic continent has contracted by an average of 120 kilometres, says Abram.

While much of the world's focus has been on the loss of winter sea ice in the Arctic, Abram told the conference, in just a decade the decrease in the Antarctic is equivalent to that lost in the northern hemisphere in the past 45 years. Even more alarming is the projection that Antarctica could possibly experience summers that are essentially free of sea ice before even the Arctic, which is projected to reach that point before 2050.

"It's really serious," says Abram. "This is a major part of the Earth's system that is changing, and it's changing incredibly quickly. We don't fully understand why it's changed so quickly, and that worries me in terms of the sort of surprises that might be ahead."

Global effects

Of particular concern is that what happens in Antarctica doesn't stay in Antarctica. The Southern Ocean around the continent has currents that drive the distribution of heat,

oxygen, nutrients and carbon dioxide as they are transported around the globe. "There is now modelling evidence and observational data that points to a slowdown of that overturning circulation around Antarctica," says Abram.

What that means for the world's climate and the wildlife that relies on this circulation is still unknown. However, researchers expect impacts throughout the food chain, from krill up to whales and penguins. There have already been mass deaths of emperor penguin (*Aptenodytes forsteri*) chicks after the early break-up of sea ice.

Nearby continents such as Australia are already beginning to see the impacts of climate disruptions in the form of dry, hot spells as well as winter blasts of cold when the southern polar vortex is pushed north.

Alex Fraser at the University of Tasmania says stormier weather in the Southern Ocean will also result in more waves, which will probably lead to greater damage to the less solid outer edges of the sea ice, known as the marginal ice zone – a worrying feedback loop.

The sea ice still present in Antarctica may be in worse shape than even the loss of coverage suggests, says Doddridge, because researchers suspect it is thinning.

"As it gets thinner, it gets weaker and it becomes more susceptible to wind break-up, to wave break-up and to not growing back. We may be rapidly getting to the threshold where it all smashes," he says.

Beyond fears over sea ice, an even bigger concern is looming: what will happen to the kilometres-thick ice sheets that cover Antarctica's landmass? Normally, sea ice plays a crucial role in preserving these sheets, both by forming a protective apron around the continent that keeps ocean waves away and by keeping water around the continent cooler.

"If we start to break up or to disintegrate these ice shelves, the ice on the continent can start to flow more quickly into the ocean," says Sarah Thompson, also at the University of Tasmania. "So we get a much larger magnitude sea level rise, more quickly."

"This is a major part of the Earth's system that is changing, and it's changing incredibly quickly"

Thompson spent the last Antarctic summer at the Denman-Shackleton ice shelf and says there is growing evidence that it is being weakened by warmer water intruding under the areas where the glacier extends over the ocean.

That is bad news – if the Denman glacier were to completely melt then it would contribute 1.5 metres to global sea level rise.

To investigate, her team drilled through 200 metres of ice to reach the ocean below, measuring the 800 metres of water there for the first time. The results were sobering.

"We knew that warmer modified circumpolar deep water was in the vicinity, but we had no idea whether it was actually getting into the cavity under the ice shelf or not," says Thompson. "Our results now show that it is."

While it is just one data point, she says it does appear that there is significant melting of the glacier on its underside.

Warm water intrusion

"We think that at that site, we're probably getting about 2 metres of melting at the base of this ice shelf on an annual basis," says Thompson. The fear is that number may grow as sea ice retreats and warmer waters intrude further under the shelf. "As soon as we remove the sea ice cover, you have more absorption of solar radiation into the ocean. The winds and the swell can have a greater impact on the ice shelf itself, so there are a number of positive feedbacks that happen as soon as you remove that ice cover," she says.

"You can get these really big ecological tipping points because of loss of sea ice," says Sharon Robinson at the University of Wollongong, Australia. "You can bring all those things together and there's a chance that we don't notice the connections until the system has really gone catastrophically bad."

What unfolds for the global climate in the coming decades is, to a significant extent, going to depend on whether supposed one-in-a-billion-year events like the 7 sigma sea ice contraction continue to happen every year.

The consensus of researchers at the summit is that, while we may see years with less or more sea ice, a tipping point has been passed. This means there is an extreme urgency in understanding all the consequences of the regime change underway.

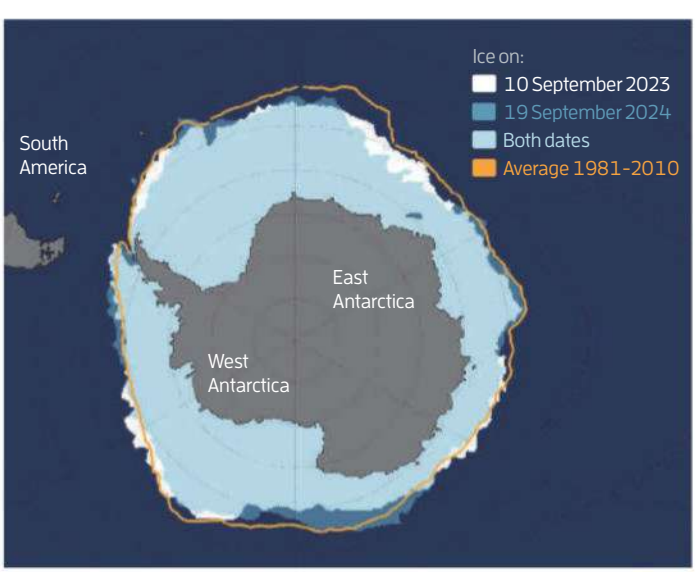
"I don't think it's going back to normal," says Abram. "I think the evidence is pointing to the rapid loss of sea ice because the ocean is taking up heat. Once you get that heat into the ocean, it holds on to it."

Doddridge says that something may have permanently shifted, and the maximum sea ice extent is unlikely to return to pre-2023 levels. "We played that game in 2024, waiting for sea ice to return to normal, and it didn't happen."

He sums up the situation with one very simple, very unscientific word: "Grim."

Chilling statistics

The Antarctic's maximum sea ice levels hit a record minimum in 2023, and fared little better in 2024, compared with long-term averages



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Astrobiology

Life on Mars could be surviving in an area deep underground

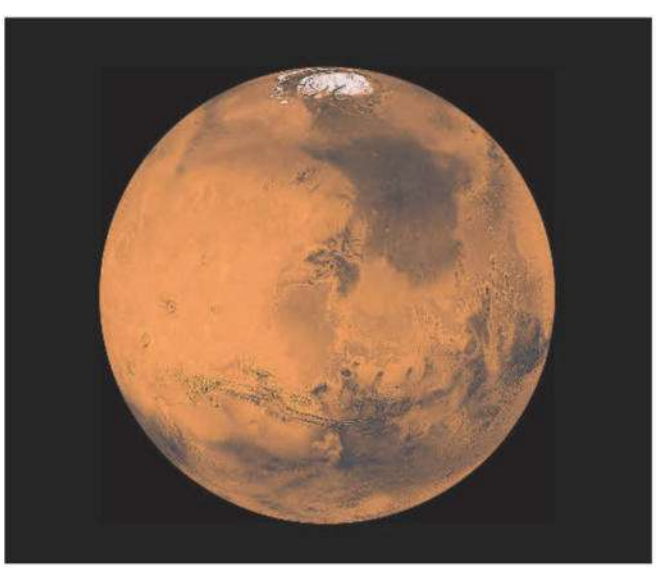
Jonathan O'Callaghan

A SPECIFIC region on Mars has been identified as a potential location for current life – with the organisms living far beneath the surface.

Andrea Butturini at the University of Barcelona and his colleagues have investigated possible locations on Mars that could host living organisms, focusing on areas that might have the right amounts of water, heat and chemical energy necessary for life to exist.

Taking data from orbiters and rovers that have visited Mars, the researchers found that Acidalia Planitia – a 3000-kilometre-wide plain in the planet's northern hemisphere – seems to have the right conditions for methanogens, methane-producing bacteria, kilometres beneath the surface. "[It is] a promising target area for future missions in the search for extant life in Mars' subsurface," the researchers write.

The Acidalia Planitia is in the darker region towards the top right of this image of Mars



NASA/JPL/USGS

Methanogens on Earth are found in many environments, including deep in the oceans. Some of these locations, such as very salty pockets of water at the sea floor, are "analogs of a hypothetical habitable Martian subsurface", write Butturini and his colleagues.

The low pressure and temperature at the surface of Mars – NASA's Perseverance rover experiences a range of about -93 to 17°C (-136 to 62°F) – make the possibility of life there remote. But in the subsurface, remnant water from the planet's past, plus heat and chemical energy produced by the radioactive decay of elements such as thorium left over from the planet's formation, could provide the ingredients for life to survive.

"There's enough energy to, in theory, fuel life very slowly," says Jon Telling at Newcastle University, UK. "The dividing times of bacteria might be hundreds of years," he says, whereas bacteria in laboratories on Earth "under ideal conditions can divide and grow in 20 minutes".

Using data from Mars orbiters, Butturini and his colleagues identified several regions as having an abundance of thorium that could provide this energy. Matching this with the distribution of ice picked up by missions like China's Zhurong rover, the "most robust target area is the southern Acidalia Planitia at mid latitude", they write, specifically between 4.3 and 8.8 kilometres deep, where the conditions could support liquid water mixed into the Martian soil because of the predicted temperature of 0 to 10°C (32 to 50°F) (arXiv, doi.org/nt75).

> "The potential for subsurface sites to host an ecosystem is not science fiction"

"The potential for subsurface sites to host an ecosystem independent of the surface is not science fiction," says Telling.

However, accessing such a deep location to see if there is life there would be difficult. "We can barely do that on Earth," says Telling. "It's going to be hard to drill down to those levels without major crewed missions."

The Rosalind Franklin rover from the European Space Agency (ESA), due to launch in 2028, will include a drill, but that will only penetrate 2 metres. Whether any methanogens several kilometres below the surface would produce evidence of life at this shallower depth is unknown, says Kevin Olsen at the University of Oxford.

"If you want to look for life alive today on Mars, you've got to look deep down," says Telling. ▮

Technology

Altering one number among billions can destroy an AI model

Matthew Sparkes

AN ARTIFICIAL intelligence model can be made to spout gibberish if a single one of the many billions of numbers that compose it is altered.

Large language models like the one behind OpenAI's ChatGPT contain billions of parameters or weights: numerical values used to represent each "neuron" of their neural network. These are what get tweaked in training so the AI can learn skills like generating text. Input is passed through the weights, which determine the most statistically likely output.

Adding more parameters to AIs boosts performance, but also pushes up electricity demand. So a process called pruning is carried out to assess which neurons have least effect and can be excised.

Now, Colorado Reed at Apple and his colleagues have found that some neurons, termed "super weights", are essential. In experiments on Meta's Llama-7B model, which has 7 billion parameters, pruning a specific super weight destroys the model's ability to generate text, "resulting in qualitatively and quantitatively gibberish responses", the researchers write.

Conversely, pruning 7000 other weights found to have the greatest impact on the output – but keeping the one with the most impact of all – affects the ability of the AI model to correctly predict the next word in portions of text by no more than a few percentage points. So, the super weight was more important to performance than the next 7000 most important parameters combined (arXiv, doi.org/nt76).

Yingzhen Li at Imperial College London says it makes sense that a single weight could have a huge influence, given that subsequent weights copy and work with what a network's first weights output. "If the original early layer's outputs are big, and you destroy them, then the entire model is messed up," says Li. ▮

Bird flu may be adapting to become more infectious to humans

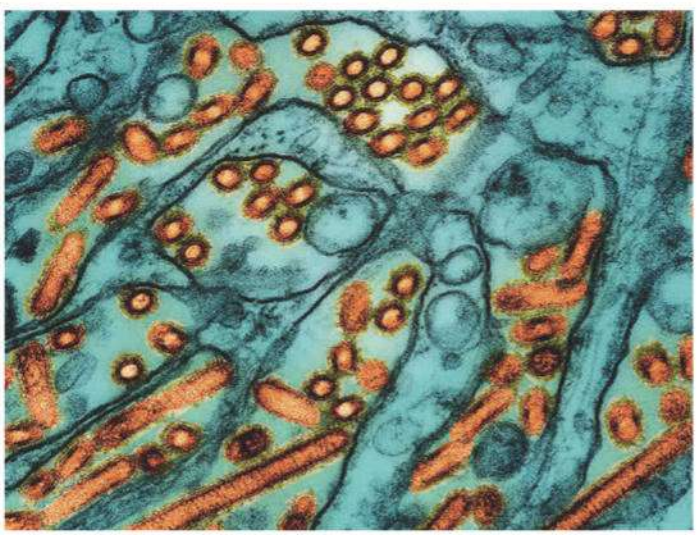
Three people in North America without known animal exposures have tested positive for H5N1, and samples from two of them suggest the virus is adapting to humans, says **Grace Wade**

THE threat of the deadly H5N1 bird flu virus adapting to humans has been inching closer to reality all year, and we may be nearing an inflection point. Three cases in humans have happened in scenarios that public health officials are concerned could lead to a pandemic in people.

"There is no clear evidence yet of human-to-human transmission, but I will not be surprised if we obtain conclusive data of such an event soon," says Seema Lakdawala at Emory University in Atlanta, Georgia. "The more the virus spills over into humans, the more likely it is to gain the potential for sustained transmission."

In the US, H5N1 has spread through dairy cows, bringing it into close proximity with people. Since January, 53 people there have tested positive for H5N1 after interacting with sick cows or chickens. Two other people have contracted it despite reporting no exposure to animals.

The Missouri Department of Health & Senior Services announced one of these cases on 6 September in someone who had been hospitalised for another reason when routine flu surveillance detected H5N1. Genetic sequencing showed a rare mutation in the virus, which early analysis suggests may slightly improve



CDC AND NIAID

The H5N1 avian flu virus (orange) can mutate to become more transmissible

H5N1's ability to bind to influenza receptors that are more common in humans than birds.

Another person in their household also developed flu-like symptoms on the same day. While they weren't tested for influenza, blood tests showed they had antibodies for H5N1, raising the possibility of human-to-human transmission. However, the US Centers for Disease Control and Prevention (CDC) says that given the timing of their symptoms, it is more likely that the two people were exposed to the same source, such as a wild bird.

The second case in a person without animal exposure was a child in California, announced the CDC on 22 November. The individual tested positive for other common respiratory viruses as well, illustrating a worrisome scenario. If one of these viruses were another type of influenza, it could swap genetic material with H5N1, potentially making it more transmissible to humans, says Richard Webby at St Jude Children's Research Hospital in Tennessee. There is no reason to think this occurred, but the likelihood of it happening in future will increase as the US enters flu season.

~900

people have had H5N1 since 2003 and about half died from it

Another case of H5N1 was announced on 13 November in a teenager in British Columbia, Canada. The adolescent, who had no underlying health conditions, has been in a critical condition at British Columbia Children's Hospital. It isn't clear how they contracted the virus. A pet dog in their household that was sick around the same time tested negative for influenza, said Bonnie Henry at the British Columbia Ministry of Health in a press briefing.

Genetic sequencing of the virus infecting the teen revealed mutations at two sites crucial for receptor binding. We don't yet know the effect of these mutations, but previous research shows that changes along these sites can improve a virus's ability to bind to influenza receptors that are more prevalent in humans than in birds. "This does show that under a natural infection, this virus can make changes at those critical positions," says Webby.

All three of the infections seem to have been a dead end for the virus. Yet they underscore how close H5N1 has come to developing mutations that could enable it to transmit between people. Of the more than 900 people globally to have reportedly had the virus since 2003, roughly half died from it, so it must be taken seriously. If H5N1 does gain the ability to pass from person to person, we may be in for more lockdowns and a vaccine rush to stave off a full-blown pandemic. ▮

Older people may have better immunity against bird flu virus

If the H5N1 bird flu virus does spark a pandemic, older people could have better immunity than younger people.

In previous clusters of H5N1 cases, older people were less likely to catch the virus than younger individuals. This could be because older people have had more exposure to flu strains that are closely related to H5N1 – H1N1 and then H2N2, which dominated globally until 1968.

To study how past infections have shaped immunity to H5N1, Scott Hensley at the University of Pennsylvania and his colleagues analysed blood samples from 121 people from Philadelphia, aged between 19 and 90.

About half of these people were born before 1968, making them 56 or older today. Almost all of this group would have caught H1N1 or H2N2 during their first flu encounter.

People born before 1968 had about three times as many key antibodies against H5N1 than those born later (medRxiv, doi.org/nt6r). These antibodies would reduce the risk of severe disease and death from an H5N1 infection, says Marc Veldhoen at the University of Lisbon in Portugal. But the immune system wanes with age, so older people may still be at greater risk of severe symptoms. Carissa Wong

Human evolution

Early human species lived side by side

Footprints preserved on a lake shore in Kenya seem to be from two ancient hominin species, showing they lived there at the same time about 1.5 million years ago, finds **Michael Marshall**

AN ANCIENT lake shore in Kenya appears to record two species of ancient humans walking over the same ground within days of each other. It is one of the most dramatic demonstrations ever found that the world was once home to multiple hominin species living side by side.

"It's really exceptional that we find this evidence for two different species walking across that surface," says Kevin Hatala at Chatham University in Pittsburgh, Pennsylvania.

Hatala and his colleagues have discovered a trackway of 12 footprints preserved in a dried-out layer of sand and silt in Koobi Fora, Kenya, near the eastern shore of Lake Turkana. It appears to have been made by one individual walking in a straight line, and the sediment has been dated to about 1.52 million years ago.

There were also three isolated prints near the main group, seemingly made by three different individuals. The lack of signs of mud cracking or overprinting of tracks with others indicate that the prints were all made at about the same time. "These sites probably capture a window of time anywhere from minutes to a few days," says Hatala.

The isolated prints resemble those left by modern humans: the heel struck the ground first, then the foot rolled forwards before pushing off with the sole. Hatala and his colleagues suggest that these were made by *Homo erectus*.

In contrast, the continuous trackway was made by a more flat-footed hominin. Hatala and his colleagues suggest this could have been *Paranthropus boisei*, another kind of hominin that lived in the region (*Science*, doi.org/g8scf4).

"With footprints, you can never be 100 per cent sure who made them," says Ashleigh Wiseman at University College London. However, *H. erectus* and *P. boisei* are the only hominins whose remains have been found in the area.

If the trackway really was made by a *P. boisei* individual, it shows that they walked bipedally, says Wiseman. While skulls, arm and leg bones have been attributed to *Paranthropus*, she says, "we have never found a skull in association with the rest of the skeleton". That means we know little about them apart from their heads, and their walking style has been a mystery. The trackway changes that: "It's unequivocal evidence of walking on two legs," says Wiseman.

These two species were very different. *H. erectus* was one of the earliest members of our genus, *Homo*. They had larger brains than earlier hominins and became the first of the group to travel outside Africa. They are also thought to have eaten a varied diet that included large animals. *P. boisei* were small-brained with large teeth and jaws, apparently adapted to eating chewy foods like grasses.

Hatala and his colleagues have looked at other known footprints from the same region covering about 100,000 years and say they match either one species or the other. "We're guessing that there was maybe low to neutral levels of competition between them, if they were able to coexist for more than 100,000 years," he says. ▮

L: NEIL T. ROACH; R: KEVIN HATALA/CHATHAM UNIVERSITY

A footprint thought to have been made by a *Homo erectus* (below) has been found less than a metre from a track of footprints (left) thought to be from a *Paranthropus boisei*

Health

A dose of fear can bring down inflammation levels

PEOPLE say laughter is the best medicine, but a bit of fear might be a strong contender, as getting spooked in a haunted house seems to lower people's levels of inflammation.

Marc Andersen at Aarhus University in Denmark and his colleagues looked at 113 people who spent 1 hour in a haunted house attraction in the city of Vejle in Denmark. They drew blood from the participants right before and after they made their way through the house's 50 rooms, which were filled with clowns, zombies and butchers with pig masks wielding chainsaws. The researchers also took blood samples three days later.

They focused on the 22 participants who had elevated inflammation – measured by levels of a marker called C-reactive protein (CRP) – before entering the haunted house. Three days after the visit, 18 of these people had reduced CRP levels (*Brain, Behavior, and Immunity*, doi.org/nt7k).

"We know that low-grade inflammation in chronic form is unhealthy", so reducing it could have benefits, says Andersen. The study didn't control for stress, alcohol consumption or menstrual phase, which can affect CRP levels.

"I would hesitate to say that if you watch scary movies, you can extend your lifespan," says Eric Shattuck at Florida State University in Tallahassee. However, social stimuli that conjure up terror, such as horror films, may temporarily lower inflammation, he says.

"I would hesitate to say that if you watch scary movies, you can extend your lifespan"

This could partly explain why some people enjoy such experiences, says Shattuck, but this is probably more related to the adrenaline rush they experience.

While inflammation has been linked to many health conditions, including heart disease and dementia, it is also a vital part of the immune response. "I'd imagine that there's a Goldilocks effect," says Shattuck. "We wouldn't want to downregulate inflammation to the point where [it's] less effective in helping us fight off infection." ▮

Kamal Nahas

Technology

Social media algorithms can change your views in just one day

Chris Stokel-Walker

MELISSA SUE GERRITS/GETTY IMAGES

Political opinions can be changed by exposure to polarised views

THE algorithms behind social media platforms can change your attitude towards people with different political views in just one day, suggesting that tech companies really can have a strong influence on how we perceive others.

Most social media platforms use algorithms to sort a user's feed, generally ranking posts by someone's likelihood of engaging with them and presenting the most engaging first, but this may inadvertently be pushing people apart.

"The trend in polarisation more generally is quite concerning," says Tiziano Piccardi at Stanford University in California. "Polarisation can lead to a lot of problems, including political violence."

To investigate the issue, Piccardi and his colleagues asked 1256 US users of X (formerly Twitter) to install a web browser extension that re-ranks content on the platform.

This extension intercepted posts before they were seen by users and fed them to the GPT-4 large language model, which ranked the posts by how politically polarising they were, according to a score based on eight potentially anti-democratic expressions, such as opposition to bipartisanship. Some users were then given a greater number of polarising posts than normal, others saw fewer, while a control group saw X's usual algorithmically curated feed.

"Platforms should really consider that optimising only for engagement can be dangerous"

The researchers surveyed each participant before, during and after the experiment, which lasted 10 days, to measure their perception of people with different political beliefs.

Perhaps unsurprisingly, they found that reduced exposure to politically polarised content made people warmer to those they disagreed with politically, while greater exposure fostered harsher sentiments. What was unexpected is how quickly this occurred, with survey answers changing after just one day (arXiv, doi.org/nt72).

Changing the way content was presented didn't affect traditional engagement metrics such as likes, reposts or time spent on the platform. Participants exposed to a greater volume of polarising content also reported heightened negative emotions, including anger and sadness, during the study, but this effect disappeared in the days after the experiment.

The work highlights how important the algorithms that dictate how we consume information are to our perception of others, says Manoel Ribeiro at Princeton University. "There is an ongoing debate about the impact of existing social media algorithms," he says, and this study shows that "the last information we consume has some weight regarding our behaviour".

Tech companies should take heed, because this shows that algorithmic curation can impact polarisation, says Piccardi. "Platforms should really consider that optimising only for engagement can be dangerous."

The fact that it is possible to switch on or off polarising content demonstrates that social media platforms have a role in managing this, says Carolina Are at Northumbria University in Newcastle, UK.

One solution may be the approach taken by Bluesky, the decentralised social network that allows users to pick their own algorithms. "Bluesky adds a lot of options for people to 'self-select' into what they consume," says Ribeiro. ▮

Marine biology

Deeper waters are being touched by ocean acidification

James Dinneen

OCEAN acidification is sinking into marine regions as deep as 1500 metres, posing new threats to organisms like sea snails and cold-water corals.

Jens Daniel Müller at the Federal Institute of Technology Zurich in Switzerland and his colleagues developed a 3D reconstruction of how carbon dioxide moves through the ocean, based on global measurements of currents and other circulation patterns. They used this model to estimate how the CO_2 the oceans have absorbed since 1800, around the start of the industrial revolution, has affected deep-water acidity.

They found a clear acidification signal down to 1000 metres in most of the ocean. Some areas, such as the North Atlantic saw acidification down to 1500 metres. Some pockets of deeper water that are naturally more acidic saw even more acidification than the surface (*Science Advances*, doi.org/nt7x). Their higher original acidity reduces their capacity to absorb any added CO_2, says Müller.

ALEXANDER SEMENOV/SCIENCE PHOTO LIBRARY

Deep-sea corals like these *Gersemia fruticosa* may be at risk from ocean acidification

About half of all the acidification since 1800 occurred after 1994, as our emissions of CO_2 have risen exponentially. The magnitude of the acidification is enough to threaten organisms in large areas of the ocean. Pteropods like sea snails are at particular risk because they build their shells out of calcium, which dissolves if the water gets too acidic. The rise in acidification has also doubled the areas where cold-water corals will have trouble surviving. ▮

Health

Gene editing may be easier in utero

Treating severe inherited conditions with gene editing while a fetus is in the womb could be more effective than the same treatment after birth, finds **Michael Le Page**

DOING CRISPR gene editing while fetuses are in the uterus could make it easier to treat inherited conditions, especially those that affect tissues such as the heart or muscles.

Kiran Musunuru at the University of Pennsylvania and his colleagues have tested gene editing in monkeys and found that it was far more effective when done before birth. "What we found was astounding," he says. "It opens up the opportunity to treat diseases that have been very hard to treat after birth."

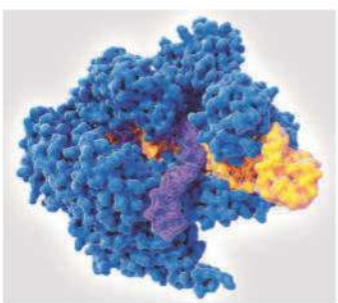
Musunuru wants to tackle inherited metabolic conditions that mean the liver can't break down certain toxins, for example. The longer these go untreated, the greater the irreversible damage that can occur to organs like the brain, and for many of them there are no effective treatments.

In these cases, it would be best to do gene editing before birth, he says. There is precedent for fetal interventions: some physical problems are now altered by surgery on fetuses as early as 16 weeks into pregnancy because the outcomes are better.

Devastating conditions

"I'm talking about those unusual cases where there's a devastating genetic condition that's not diagnosed until the pregnancy is already well established," says Musunuru. "Are we going to really wait until birth to treat? If you insist on that, then some of these patients are going to suffer irreversible harm before they're born, and they're going to be much worse off than if you were to treat before birth."

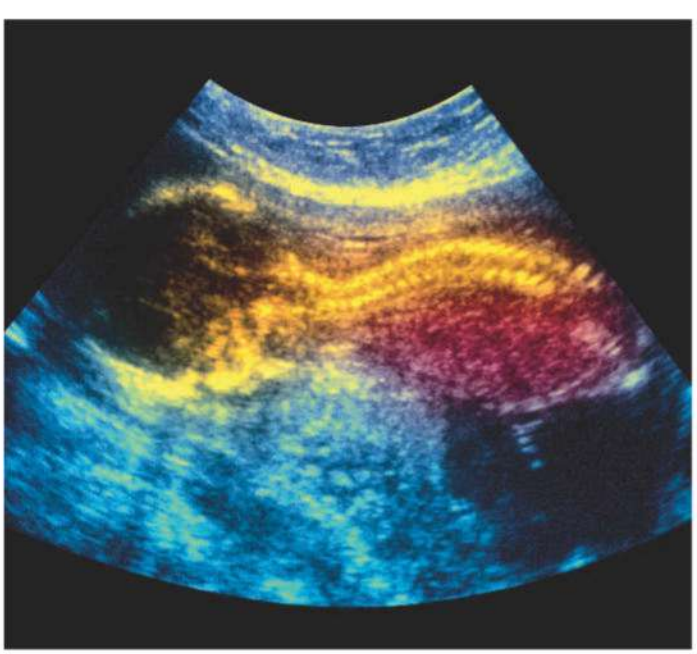
To pave the way for prenatal gene editing, Musunuru and his team are doing tests in animals including monkeys. Their approach involves using genetic messenger molecules called mRNAs that code for gene-editing machinery, packaging them into fatty parcels called lipid nanoparticles. The researchers then inject these into the umbilical cord.



JUAN GAERTNER/SCIENCE PHOTO LIBRARY/ALAMY

The CRISPR-Cas9 gene-editing complex (above) could be used to treat a fetus in the uterus (below)

"If you wait until birth to treat, some people are going to suffer irreversible harm before they're born"



SIMON FRASER/SCIENCE PHOTO LIBRARY

In adults, almost all of these nanoparticles are taken up by liver cells, meaning almost all the editing happens in those cells. For now, the only way to target tissues such as muscle is to use viruses to deliver the CRISPR gene-editing machinery, but this is problematic, not least because viruses can trigger an immune response. "The general consensus is they just don't work that well," says Musunuru.

He and his team have yet to publish their research, but he told *New Scientist* that when they injected lipid nanoparticles into monkey fetuses, there was even more editing in the liver than in adults for an equivalent dose. To their surprise, there was also extensive editing in the heart and the diaphragm muscle, and, to a lesser extent, in other muscles and the kidneys.

This means the approach could be used to treat heart conditions, and, by optimising the lipid nanoparticles, Musunuru thinks it will also be possible to get even more extensive editing in muscles to treat skeletal muscle conditions. In fetuses, it is likely that the barriers between tissues aren't yet fully established, he says, meaning the lipid nanoparticles can reach places they normally can't.

Immune evasion

Another possible factor is that fetuses are also growing quickly, says Robin Lovell-Badge at the Francis Crick Institute in London, and gene editing works better in rapidly dividing cells.

He says other groups are also working on developing prenatal gene-editing treatments. If this is done before the immune system develops, it could avoid any immune responses to viruses used for delivery and other components of the treatment.

"However, prenatal genome editing does mean that there are two patients, the fetus and the mother. This makes it more complex in several respects," says Lovell-Badge.

What's more, genetic conditions need to be identified early in pregnancy for prenatal gene editing to be a possibility. At present, such screening is done after birth, and only in a few countries and for a few conditions. But Musunuru says no one is screening fetuses for such conditions because nothing can be done if one is identified, and that this will change if there are treatment options. "It's a chicken-and-egg problem," he says. ▮

Palaeontology

Fossilised droppings reveal how the dinosaurs came to rule Earth

Christa Lesté-Lasserre

THE contents of 200-million-year-old faeces and vomit are showing how dinosaurs took over the world at the start of the Jurassic Period.

Well-preserved plants, bones, fish parts and insects embedded in ancient animal droppings suggest that dinosaurs' broad diets made them survivors in a changing ecosystem. This then led them to grow larger and establish their "dynasty on land", says Martin Qvarnström at the University of Uppsala, Sweden.

Fossil evidence shows that the first dinosaurs – with legs under the body like mammals, rather than out to the sides like lizards – appeared more than 230 million years ago in the Triassic Period. For tens of millions of years, they blended in with many other kinds of reptiles. But by about 200 million years ago, soon after the Jurassic began, dinosaurs had essentially taken over the planet, while most other reptiles vanished during the end-Triassic extinction.

To investigate what happened, Qvarnström and his colleagues examined 532 bromalites, or fossilised faeces and vomit, from dinosaurs and other animals. All were found in Poland and stored in the Polish Geological Institute.

The team estimated the age of each bromalite based on the layer of sediment it was in and used its size and shape to match it to the animal that probably produced

Fossilised dung shows that dinosaurs like Sauropodomorphs could eat newly evolved plants

L: GRZEGORZ NIEDZWIEDZKI; R: MARCIN AMBROZIK

it. The researchers then 3D scanned the fossils. "We realised that they're packed with food remains," says Qvarnström.

Using this data, the fossil record and past climate information, the researchers were able to say that the rise of dinosaurs happened in steps. First, omnivorous ancestors of the early dinosaurs started to outnumber non-dinosaurs. Then, they evolved into the first meat-eating and plant-eating dinosaurs.

At that point, an increase in volcanic eruptions and shifts in tectonic plates led to flooding and more waterways. The resulting humidity and changes to climate seem to have triggered a greater range of plants, leading to the evolution of bigger and more diverse herbivore dinosaurs, such as some Sauropodomorphs. Non-dinosaurs – like the 1-tonne, plant-eating dicynodont *Lisowicia*, whose faeces contained mainly conifer remains – were less able to adapt (*Nature*, doi.org/nt3w).

As the herbivore dinosaurs grew bigger, so did their predators. When large carnivorous dinosaurs started to appear in the Jurassic – about 30 million years after the first dinosaurs emerged – the transition to a world dominated by dinosaurs was complete, says Qvarnström.

"The study shows how climate mainly affected the dominant plants, which in turn gave opportunities for new herbivores at certain points," says Michael Benton at the University of Bristol, UK.

Technology

Data stored in diamonds could last millions of years

DIAMONDS are forever, or so the saying goes, and this may only be a slight exaggeration for gem-based systems capable of storing information for millions of years. Now, researchers have created one with a record-breaking storage density of 1.85 terabytes per cubic centimetre.

The laser pulse technique used to encode data means a diamond optical disc with the same volume as a standard Blu-ray could store about 100 terabytes of data – the equivalent of about 2000 Blu-rays – while lasting far longer than a typical Blu-ray's lifetime of just a few decades.

"Once the internal data storage structures are stabilised using our technology, diamond can achieve extraordinary longevity – data retention for millions of years at room temperature – without requiring any maintenance," says Ya Wang at the University of Science and Technology of China in Hefei.

Wang and his colleagues worked with pieces of diamond only a few millimetres long, although they say future versions of the system could be in the form of larger storage discs. Their method used ultra-fast laser pulses to knock some of a diamond's carbon atoms out of place, leaving behind empty spaces the size of single atoms that each exhibit a stable brightness level.

By controlling the energy of the laser, the researchers could make multiple empty spaces at specific sites in the diamond, and the density of those spaces influenced each site's overall brightness. "The number of empty spaces can be determined by looking at the brightness, which allows us to read the stored information," says Wang.

100
terabytes of data could fit on one diamond storage disc

The team then stored images – including Eadweard Muybridge's 1878 sequence of photos showing a rider on a galloping horse – by mapping the brightness of each pixel to the brightness levels of specific sites inside the diamond. The system saved this data with more than 99 per cent accuracy and completeness (*Nature Photonics*, doi.org/ntzd).

"In the short term, government agencies, research institutes and libraries focused on archiving and data preservation would likely be eager to adopt this technology," says Wang.

Jeremy Hsu

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Comment

Pandemic lessons

Five years after the first covid-19 cases, we need to fight back against the quiet epidemic of suppressed science, says **Dali L. Yang**

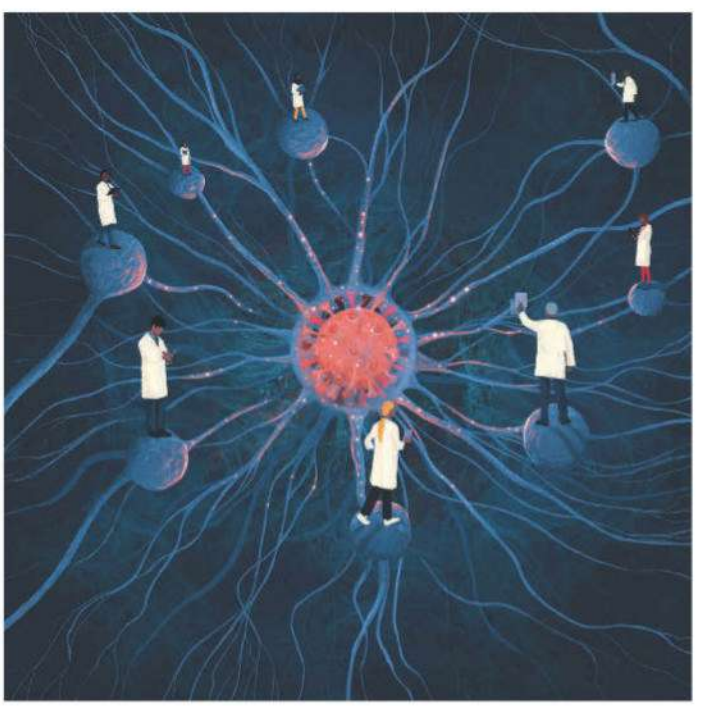
IT IS now five years since clinicians in Wuhan, China, first encountered covid-19 cases in December 2019. Hindsight makes it even clearer how the battle against the disease wasn't just a fight against a virus, but also a struggle against the political suppression of scientific evidence.

This isn't a new phenomenon. During the SARS outbreak, which started in China's Guangdong province in November 2002, local authorities initially restricted the release of information and downplayed the severity of the outbreak. In the ensuing months, the virus spread in China and overseas unhindered.

China vowed to learn lessons from SARS, and established a nationwide disease reporting system (NNDSS) to expedite early warnings and responses.

Yet the covid-19 pandemic underscored the catastrophic potential of letting political expediency override the voices of clinicians and scientists. It is well-known that Wuhan police reprimanded Li Wenliang, an ophthalmologist at a leading hospital, for sharing information that a patient had been infected with a SARS-like coronavirus.

This was the tip of the iceberg. In researching my book, I became keenly aware that the influence of political considerations and the suppression of scientific voices were much more pervasive. Instead of getting early warnings from cases reported on the NNDSS or from the health authorities in Wuhan, George Gao, the China CDC Director General, first learned of the outbreak in Wuhan on social media, while local authorities sidelined NNDSS.



SIMONE ROTELLA

On 1 January 2020, on the recommendation of experts, Wuhan began to implement a health emergency action programme to control the outbreak. In my research, I was struck by the amount of good information the health authorities had access to on 31 December 2019. Not only did clinicians recognise the SARS-like symptoms of their patients, but no fewer than four laboratories had assembled genomic sequences of the SARS-like coronavirus.

Yet authorities downplayed the severity of the outbreak, avoiding any reference to the disease's SARS-like characteristics.

Despite the emergence of a growing number of cases with the same symptoms and warnings of human-to-human transmission, local authorities froze the submission of new suspected cases to Beijing. This obstruction led to a delayed acknowledgement of the virus's severity, significantly hampering containment efforts.

Had the Chinese system handled the outbreak with transparency, Wuhan could have been spared much of the trauma of the lockdown and the course of the global pandemic might have been drastically altered, even possibly contained at its nascent stage. The effects of this delay continue to reverberate.

Transparency in scientific communication isn't merely a principle but a lifeline in public health emergencies. Yet, when political considerations thwart the dissemination of epidemic information, that lifeline is severed. Five years on, the covid-19 pandemic highlights the need for a robust international framework that champions free inquiry and collaboration. With recent outbreaks of mpox and the spread of H5N1 bird flu, this is only more urgent.

The international pandemic accord being negotiated by the World Health Assembly represents a critical step in strengthening global health security. However, challenges remain, especially around the sharing of pathogen genomic data, surveillance and equitable access to vaccines and treatments. These have pushed the agreement's finalisation into 2025, but closing these gaps is essential, to ensure the lessons of covid-19 aren't forgotten, and to prepare for future outbreaks. ▮

Dali L. Yang is author of *Wuhan: How the covid-19 outbreak in China spiraled out of control*

Future Chronicles

Fly me to the moon

We journey to 2055, when a space elevator from the moon's surface to near-Earth orbit was completed, democratising space in the process. **Rowan Hooper** is our guide

Rowan Hooper is *New Scientist*'s podcast editor and the author of *How to Spend a Trillion Dollars: The 10 global problems we can actually fix*. You can follow him on X @rowhoop

In Future Chronicles, he explores an imagined history of inventions and developments yet to come.

This column appears monthly. Up next week: Our columnists look back at 2024

EVEN as the price of space flight came down dramatically in the 2030s, the environmental and financial cost of using chemical rockets to escape Earth's gravity held back human expansion to the moon and beyond. There was also widespread anger that space exploration was becoming a preserve of the ultra-rich, leading to a desire for access to space to be democratised.

A dream, for centuries, had been to build a space elevator to take us from Earth into space without using rockets. But how could it be built, and where? The engineering challenges, along with the political hurdles, were too great. The answer was to flip the idea and build a zip line from the lunar surface to Earth orbit. All you had to do was get from Earth to the end of the line, leap on a solar tram and trundle along the track to the moon.

Rockets were still needed to reach the dangling end of the zip line, but since they didn't have to totally escape Earth's gravity, far less fuel was required. Unlike traditional designs for space elevators, the line didn't need a giant counterweight, so the stress on the cable was far less. The materials to make this a reality were available, and the political and financial case became viable by the 2040s.

Once built, people and cargo could be delivered from Earth by rocket to the zip line and then on to the moon, with the total amount of fuel needed to move something from our world to its natural satellite reduced by two-thirds. The resulting drop in price dramatically changed what could be done in space and who could go.

The base for the first lunar zip line was constructed close to the moon's south pole, on the lunar near side, where several moon bases had been established in the late 2030s to take advantage of the near-constant light at the south pole and the big reserves of frozen water in Shackleton crater.

Unlike the moon bases, which retained ties to private companies and nation states on Earth, the elevator was a shared resource. It was constructed under laws designed by NGOs For All Moonkind and the Open Lunar Foundation, and equivalent organisations in the major contributing territories (India, Japan, China and the EU).

The zip line connected to the moon via the lunar Lagrange point 1 (L1). These are regions in space where the gravity of the moon and Earth balance out, and fuel isn't needed to maintain the position of an object. In effect, they are parking lots in space, and thus extremely useful sites for depots and spaceports. The zip line – or Lunar Ladder, MoonWalk or Cheese Stick, as it was variously nicknamed – was simultaneously built from a space depot at L1 and the base on the lunar surface. The ultra-strong synthetic polymer M5 was chosen as the material, and thousands of tonnes of it were delivered to L1 for construction.

> **"All you had to do was get from Earth to the end of the zip line, jump on a solar tram and trundle along it to the moon"**

The enterprise sparked several beneficial developments. Chemical rockets, which provide enough thrust to get off a planet's surface, were still used to get to low Earth orbit, but after that, ion drives hitched a ride on the elevator and were then used to move around the solar system. These drives generate thrust by accelerating electrically charged atoms through an electric field, and were powered by solar energy. This allowed cheaper, and deeper, exploration of the great beyond.

The earliest suggestion for a space elevator dates to 1895, in a thought experiment devised by Russian space pioneer Konstantin Tsiolkovsky. "Earth is the cradle of humanity," Tsiolkovsky wrote in 1911, "but mankind cannot stay in the cradle forever." The first test of such technology occurred in 2018, with the advent of the STARS-Me project (Space Tethered Autonomous Robotic Satellite – Miniature Elevator). This took place beside the International Space Station, using a design by researchers at Shizuoka University in Japan. It consisted of two small satellites connected by an 11-metre cable with a crawler that travelled between them.

In the 2030s, when the Artemis missions to the moon began, the Gateway space station was built in lunar orbit, and this became a stepping stone to the L1 depot.

The zip line played a pivotal role in democratising space. Going to the moon for work or leisure became something almost anyone could do if they wanted. Scientific breakthroughs followed from the establishment of a research base at L1, and destructive operations such as mining were moved off-planet. Much of the polluting industrial infrastructure of Earth – especially the server farms that supported computer demand – were moved to the moon where they could be more efficiently powered by solar energy.

But more than that, the People's Zip became emblematic of the societal change that began in the 2040s, as the influence of the mega-rich waned and cooperative power grew. ▮

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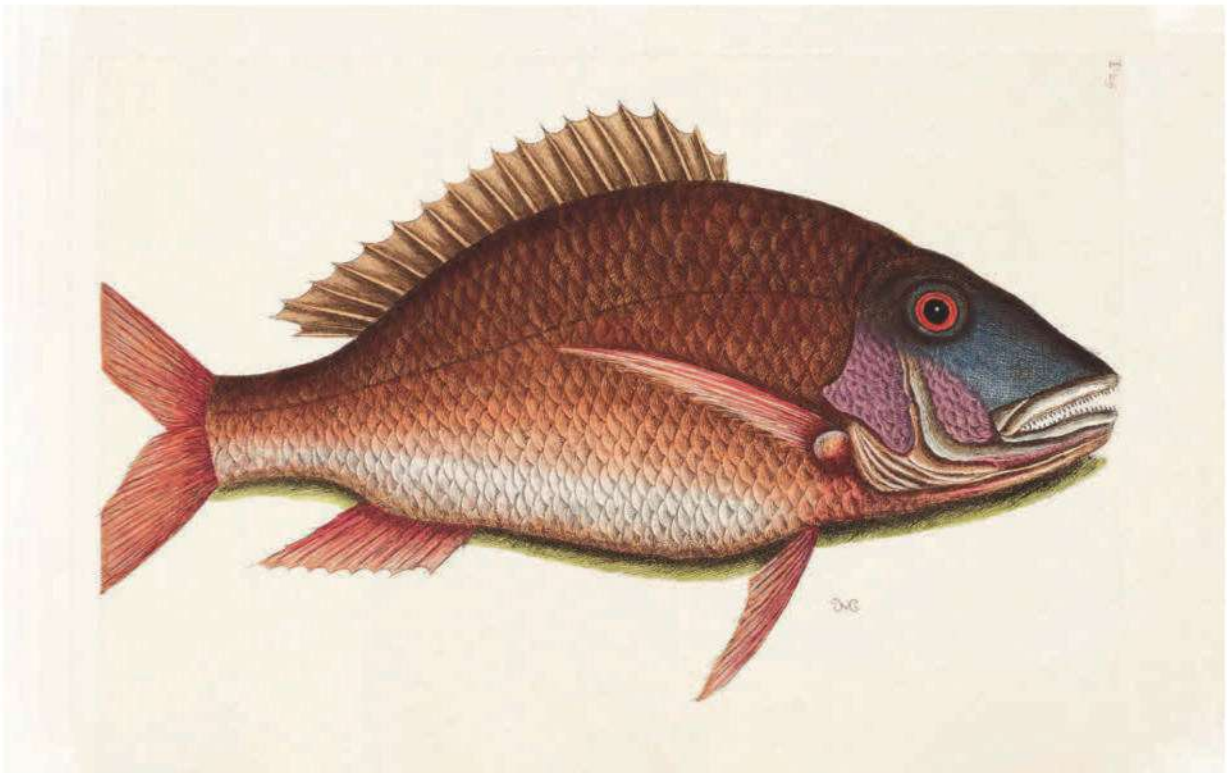

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Great Catesby

Bodleian Library Publishing
University of Oxford

THESE remarkable and intricate illustrations are the work of Mark Catesby, an English naturalist and artist who made numerous visits to North America in the early 18th century, recording the flora and fauna he saw on his travels.

His work is collected in a new book, *Catesby's Natural History* by Stephen A. Harris, an exploration of the naturalist's landmark treatise, *The Natural History of Carolina, Florida, and the Bahama Islands*. "Catesby presented his readers with illustrations of a wide diversity of plants and animals that were being discovered by Europeans in North America and the Caribbean," says Harris. "Many of these were illustrated for the first time – Catesby became the de facto authority on them."

Featuring more than 400 species, some of which are now extinct, several plates depict a plant and an animal in one image, such as the rough green snake (*Opheodrys aestivus*), shown near left, curling around an American beautyberry shrub (*Callicarpa americana*). In a similar vein, a giant hermit crab (*Petrochirus diogenes*) sits on top of what, writes Harris, is "probably" an angular sea whip (*Pterogorgia anceps*), shown bottom middle.

At top left is a colourful mutton snapper (*Lutjanus analis*), and the deciduous plant Spanish jasmine (*Plumeria rubra*) is at bottom left.

Catesby "hoped to stimulate curiosity in natural history – beyond the confines of the library", says Harris. "His work speaks to modern themes of landscape and habitat change, changing species' distributions and extinction and the value of traditional knowledge held by Indigenous people."

Tim Boddy

From the big screen...

Forget *Megalopolis* and *Madame Web*. The best science fiction films of 2024 were all horror-inflected, says our film columnist **Simon Ings**

WARNER BROS. PICTURES

Paul (Timothée Chalamet, right) and Chani (Zendaya) in *Dune: Part Two*

NO ONE, looking back at a year that brought us *Madame Web* (a Spider-Man spin-off about a clairvoyant) and the director's cuts of *Rebel Moon* parts 1 and 2 (director Zack Snyder's take on *Star Wars*) could seriously claim that big-screen science fiction is in a particularly healthy state at the moment. Cinema itself is on the ropes, financially and artistically – but I will leave it to bigger boots than mine to go galumphing across the post-apocalyptic wasteland that is modern Hollywood. Let's round up the year instead by hunting for those ever-elusive green shoots of recovery.

Not every franchise blew up in its owners' faces. Riffing off Ridley Scott's 45-year-old film series, Fede Álvarez's *Alien: Romulus* played a great first half, before trying to stuff every bit of *Alien* lore onto the screen at once. Then there was *Dune: Part Two*. At the time, I wrote a mightily sniffy review of Denis Villeneuve's adaptation of Frank Herbert's sci-fi novel. I feel kinder towards it now. It was a feast for the senses, if not for the mind.

After last year's medium-budget smash *Godzilla Minus One*, rival monster-movie projects seem to have crawled under the bed in shame. Only one poked its head above the coverlet this year: *Arcadian*, which wasn't really about monsters (magnificent as they were: an extraterrestrial fever dream, all fur and elbows and teeth), so much as the importance of being a wonderful dad (and Nicolas Cage) in the end times.

You can't beat a bit of dystopia. This year's crop is represented by the body-fascism-is-bad sermon *Uglies*, set in a future where plastic surgery is all but obligatory (because the film was just awful), and *Turn Me On* (because it was charming and clever and unexpectedly moving and cost about threepence; some day soon, believe you me, all films will be made on this budget, so we had better start taking notes.)

Incredibly, given the amount of coverage it generated elsewhere, artificial intelligence got the thinnest of big-screen treatments in 2024. The overbearing-going-on-psychotic digital assistants in *AfrAId* and *Subservience* were but shallow replies to 2022's killer-doll hit *M3gan*. Sci-fi romance *Wonderland*, whose lonely characters become ever more captivated by the digital dead, was more interesting.

But to be frank (and you may clutch your pearls now), I think science fiction has had its day. If it is green shoots of cinematic recovery you want, then you need to shuffle along the aisle to the horror section, and there you will encounter what has to be the most memorable film of the year, *The Substance*.

"*The Substance*, starring Demi Moore, is the most memorable film of the year: daft and utterly disarming"

Fading Hollywood star Elisabeth Sparkle has lost her daytime TV gig. A simple injection splits her into two, and one of her (played by Margaret Qualley) is a lot younger than the other (played by Demi Moore). Nothing can prepare you for the film's deliberate swerve into silliness and sheer exuberance. It gleefully resuscitates the monster-movie genre, not by contributing to body horror, or Hollywood satire, or films about the male gaze, but by beating on all three like a 5-year-old let loose on a piñata. It is daft and utterly disarming.

Other horror-inflected gems this year included *Humane*, a delightfully nasty satire about what we are willing to sacrifice to solve the climate crisis (clue: relatives) and *It's What's Inside*, a body-swapping dark comedy about a souped-up board game.

We end our run-through of 2024 films, though, with Francis Ford Coppola's *Megalopolis*, a film of such baffling over-complexity and mind-numbing tedium you may wonder how I dare mention it in practically the same breath as *The Substance*. But *Megalopolis* has, in its own, unlovely fashion, something significant to to say about our technological future. Its tale of the wholesale reinvention of "New Rome" is about the future as Elon Musk would have it.

It pits the millenarian thinking of Adam Driver's Ayn Rand-inspired architect against the grubby, make-do-and-mend of Giancarlo Esposito's mayor. In execution, it resembles nothing so much as a nasty accident during a Christmas commercial: a catastrophic collision of dance numbers, portentous pouting and whirling bling. Conceptually, however, it is frighteningly on the button.

2024 also saw the rerelease of *Threads*, Barry Hines's famously traumatising BBC docudrama about a nuclear strike on a UK city. This cost £400,000 in 1984 – just $1.5 million in today's money. *Madame Web* cost $100 million or so. Every few decades, the film industry must bankrupt itself before realising that a film is simply a kind of story, and good stories don't need to cost the earth. ▮

...to the small

This wasn't a stellar year for science fiction television, but there were diamonds to be found amidst the rough, says our TV columnist **Bethan Ackerley**

DESPITE it feeling like there is more to watch on TV than ever before, it hasn't been a banner year for sci-fi on the small screen. Too many shows have been simply OK, with their moments of flare outweighed by exposition dumps and plot holes a mile wide – not to mention a few expensive, high-profile disappointments that have cluttered up streaming services (hello *Dune: Prophecy*, I'm looking at you).

Nevertheless, there are always treasures to be found if you are willing to do some digging. One word-of-mouth hit this year was *Supacell* (Netflix), a superhero series set in south London that follows five ordinary people with extraordinary abilities. For all its similarities with previous shows about genetically gifted superhumans, the premise of *Supacell* is much more unique: the characters gain their powers from a mutation to the gene that causes sickle cell disease.

The series walks a fine line between its fantastical main plot – time-traveller Michael (Tosin Cole) witnesses a future where his fiancée is dead and he is facing off against strange hooded figures – and its sharp social commentary about the experiences of Black people in the UK.

Not one but two standout series of 2024 were heavily centred on underground bunkers. First to arrive was the ultra-violent, hilarious *Fallout* (Amazon Prime Video), set in the post-apocalyptic world of the popular video game series. In this alternate history, the US became a nuclear playground from the 1950s onwards.

Those rich enough to have purchased a place in a bomb shelter have spent generations waiting to reclaim the surface world. When Lucy (Ella Purnell) is forced to leave the safety of her subterranean home, she enters a wasteland populated by cannibals, militias and gunslinging ghouls. It is far from hard sci-fi, but *Fallout* is a blisteringly entertaining trip to the end of days.

NETFLIX

APPLE TV+

Above: Nadine Mills plays a nurse, Sabrina, in superhero series *Supacell*. Below: Juliette ventures into the outside world in *Silo*'s second season

The second bunker-based highlight of 2024 was *Silo* (Apple TV+), which began airing its second season last month. Based on Hugh Howey's novel series of the same name, it takes place in – you guessed it – an enormous silo beneath the surface of a poisoned planet. Having uncovered a conspiracy in the highly stratified society of the silo, engineer Juliette (Rebecca Ferguson) is out to learn all she can about the world beyond its confines.

Season one of *Silo* was self-satisfied and inconsistent, which makes this strong second outing all the more delightful. Having seen nine of the 10 episodes this season, I can say that while it still isn't a perfect show, it has matured into something compelling that is capable of delivering on the big ideas we need in our sci-fi series.

For another ideas-heavy adaptation, try *3 Body Problem* (Netflix), which stuck a near-impossible landing this year by bringing the complexities of Cixin Liu's esteemed novels to TV. With scientists dying in droves and strange anomalies blowing up all known theories of physics, a crew of friends reunite after years apart to tackle an extraterrestrial threat to Earth.

Touching on everything from China's cultural revolution to the philosophical challenges of climate change, this series doesn't talk down to viewers. It is also bold enough to make changes to its source material – in a time when TV series can get away with simply rehashing existing books and films, this approach is something we need a lot more of.

We may not have had a wealth of sci-fi gold this year, but the final days of 2024 have provided one more gift. *The Listeners* (BBC iPlayer), based on Jordan Tannahill's speculative novel, is near enough a masterpiece. English teacher Claire (Rebecca Hall) is plagued by a low humming noise that no one else can hear. No obvious medical cause can be identified.

Claire is increasingly unsettled by the sound, but when she learns that her troubled student Kyle (Ollie West) can also hear it, they strike up a dangerous friendship. Part domestic drama, part psychological thriller, *The Listeners* is hard to pin down, but its take on conspiracies, community, faith and seduction is singular.

Here's to many more series like it in 2025.

Let the games begin

From horror on a North Sea oil rig to the adorable Astro Bots, our video games columnist **Jacob Aron** had a lot of fun in virtual worlds this year

COMPARED to some years (I am thinking of 2023 and its wealth of offerings, from *Cocoon* to *Viewfinder*), 2024 has been a bit slower for must-play video games, particularly for the science and technology-themed titles I like to highlight for a *New Scientist* audience. But that isn't to say there was nothing to enjoy – far from it! – so here are my picks for the year.

TEAM ASOBI

Astro Bot is a charming platform game – and a love letter to PlayStation

Astro Bot (*Team Asobi*)

I suspect this charming platformer (see main image) will be at the top of many game-of-the-year lists, and it would certainly deserve that spot. It is an unashamed love letter to all things PlayStation, with the titular Astro Bots travelling the stars in a spaceship that resembles a PS5 before it is blown up by aliens, scattering parts and robots everywhere. Your job is to jump, climb and swim your way through a series of levels to find console parts and robots dressed as Sony characters to reunite everyone. It all looks gorgeous and is incredibly fun. *PlayStation 5*

Balatro (*LocalThunk*)

This is a game for probability fiends. You are dealt a hand of cards and must score the highest you can according to standard poker rules. So far, so boring – until you add the jokers. Each joker card has a special power, from the mundane (slightly increase your score) to the extreme (copy the ability of other jokers). Your job is to assemble a set of jokers that increasingly breaks the game, boosting your score, while playing the odds to hit ever higher score goals. Throw in other cards that offer one-time effects or other upgrades, along with slot machine-style visuals and sounds, and you will be playing this for a long time. *PC, PlayStation 4 and 5, Xbox Series X/S and One, Nintendo Switch, Android, iOS*

Final Fantasy VII Rebirth (*Square Enix*)

As I said in April, this second title in a remake trilogy of the iconic *Final Fantasy VII* has a lot to say about environmentalism. It is set in a world that runs on mako, a form of spiritual energy drawn from the planet itself, and follows a band of eco-terrorists as they attempt to fight the evil Shinra power company and prevent it from over-exploiting mako. What makes it interesting is that mako can be read either as a nuclear power analogue or stand-in for oil, with quite a different message depending on your interpretation. *PlayStation 5*

Still Wakes the Deep (*The Chinese Room*)

This period piece set on a 1970s North Sea oil rig is dripping with atmosphere, Scottish dialogue and tentacles. I am not normally a fan of the "walking simulator" genre, in which you slowly move around an environment to uncover a story, but this one had me hooked. *PC, PlayStation 5, Xbox Series X/S*

Botany Manor (*Balloon Studios*)

An utterly charming puzzler in which you explore a 19th-century English manor to put together a herbarium of weird and wonderful flowers. You play as botanist Arabella Greene and subtly learn her story through the course of play, such as how she has fought against the male-dominated scientific establishment to make her name as a researcher in her own right. *PC, PlayStation 4 and 5, Xbox Series X/S and One, Nintendo Switch, Android, iOS*

Warhammer 40,000: Space Marine 2 (*Saber Interactive*)

I grew up playing the Warhammer 40,000 tabletop game, which mostly involves spending vast sums on plastic soldiers and painting them poorly, so it is always a world I am happy to return to in the slightly cheaper realm of video games. This title is actually a follow-up to a decade-old original, hewing surprisingly close to its story, which I had mostly forgotten. None of that matters – the point here is to strap on your power armour, hoist a gun the size of a small car and blast through hordes of alien scum. *PC, PlayStation 5, Xbox Series X/S*

Flock (*Hollow Ponds*)

Soar through the skies as you search for fictional bird species, classifying each one by its unique characteristics. Some are easy to track down, simply flying by, while others require more dedication and puzzle-solving. You can also team up with friends to fill out your bird guide together. *PC, PlayStation 4 and 5, Xbox Series X/S and One*

Editor's pick

The epidemic of myopia raises many questions

16 November, p 32

From Sam Edge, Ringwood, Hampshire, UK

The prospect that half the world will have myopia by 2050 might be good news for opticians, but is alarming for the rest of us. The fact that encouraging children to spend more time outdoors helps avoid myopia adds to the list of benefits of doing so, reinforcing the need not to shackle them to the house.

There is also evidence that sending children to formal school too early in life results in worse academic outcomes. Countries like Sweden and Estonia don't start formal school until around the age of 7 while the UK and many others start at 4 or 5. Given children may spend more time inside at school, I wonder if there is a correlation with early-onset myopia.

Another possible factor is that more parents need to work, so more preschoolers are in nursery where the logistics make it harder to allow them much time outdoors.

From Ian Simmons, Westcliff on Sea, Essex, UK

I favour the idea, one of several raised, that exposure to wide open space outdoors is what reduces myopia rates in children, rather than light exposure. Indoors the eye can only look as far as the walls, while outdoors it needs to deal with vistas of hundreds of metres, if not kilometres. Without this, is it surprising eyes become adapted to seeing close up at the expense of being able to see what is far away?

Was this research really necessary?

2 November, p 48

From Emily Trunnell, People for the Ethical Treatment of Animals

Missing from the item about experiments in which researchers used monkeys to predict US election outcomes was the fact that they strapped them into restraint chairs for hours. Those who defend animal experiments claim that animals are only used for important research questions and when there is no alternative, but what was described is case-in-point that those words are meaningless platitudes.

Mars colonists could just head for the desert instead

16 November, p 40

From Bryn Glover, Kirkby Malzeard, North Yorkshire, UK

I was glad to read Kelly and Zack Weinersmith's debunking of Elon Musk's idea of million-strong colonies on Mars. If people insist on living in hostile places either in domes or underground, the world has numerous deserts where they could establish themselves, with any problems concerning temperature, pressure, radiation or communication with the rest of us easily solved. The great urge to leave Earth and found colonies elsewhere is simply a manifestation of denial of the monstrous problems we shall all need to face here in the near future.

Early humans probably didn't need baby slings

9 November, p 32

From Beverley Rowe, London, UK

Your look at possible botanical craftwork pre-dating the Stone Age mentioned baby slings as a possible example. However, furry mothers don't need them: their babies have something to cling to. When did humans lose their fur? I suspect a lot of other botanical craft came before baby slings.

From Richard Grimmer, Trowbridge, Wiltshire, UK

If anyone still feels that tool use is what turned our animal ancestors into our human ancestors, may I suggest that the dividing line was when the first hominin used a leaf as toilet paper, though I doubt that any evidence survives.

For the real facts, look to the philosophers

Letters, 9 November

From Terry Klumpp, Albion, Victoria, Australia

One reader suggested a remedy to the issue of poor fact-checking in popular science books of sticking to the greatest scientist-writers. I contend we should instead turn to the writing of philosophers of the impeccable logic of Bertrand Russell or David Hume, say, who are better able to discern fact from fiction and hyperbole.

Athenian democracy was highly questionable

5 October, p 32

From Stuart Leslie, Dorrigo, New South Wales, Australia

No one should base ideas of democratic reform on the belief that ancient Athenian "democracy" was an ideal form of government.

Athens hardly invented democracy: there were very large polities in Eurasia that show no trace of hierarchy and must have been organised by council and consensus thousands of years before Athens, whose government never involved more than 17 per cent of the population.

Socrates, held to be the wisest man in the world, didn't think Athens better than any other government. It was plagued by factions, demagogues, threats, violence and continual attempts to get opponents exiled or put to death. It ordered the massacre of two cities because they withdrew from an alliance. It decided to invade Syracuse, resulting in the loss of an entire Athenian army, and forced the continuance of war against Sparta, leading to final defeat. It wasn't a great form of government, rather very irrational and ultimately self-destructive.

Why insects may not make good food for farmed fish

Letters, 16 November

From Dustin Crummett, The Insect Institute

On the idea that insects hold the answer to the dilemma of how best to feed farmed fish, peer-reviewed research I recently coauthored, along with industry statements, casts doubt on the ability of insects to compete economically with fishmeal made from wild-caught fish.

If insects don't compete with fishmeal, obviously they won't solve the serious environmental challenges posed. Even if they did, they score worse than the status quo on some environmental metrics, such as greenhouse gas emissions.

I see nothing worthwhile in free-energy principle

19 October, p 32

From Denys deCatanzaro, Professor emeritus of psychology, neuroscience and behaviour, McMaster University, Canada

Neuroscience progresses through rigorous empirical measures of neural anatomy, circuitry and chemistry; studies of relationships to behaviour; and comparisons among species. Where is there added value from nebulous and simplistic abstractions such as Markov blankets and the free-energy principle?

These ideas came primarily from philosophy rather than hard science. Their main proponent, Karl Friston, is quoted saying that "...all you can do with the free-energy principle is apply it. You... can't falsify it, you can't critique it". So, essentially it isn't testable.

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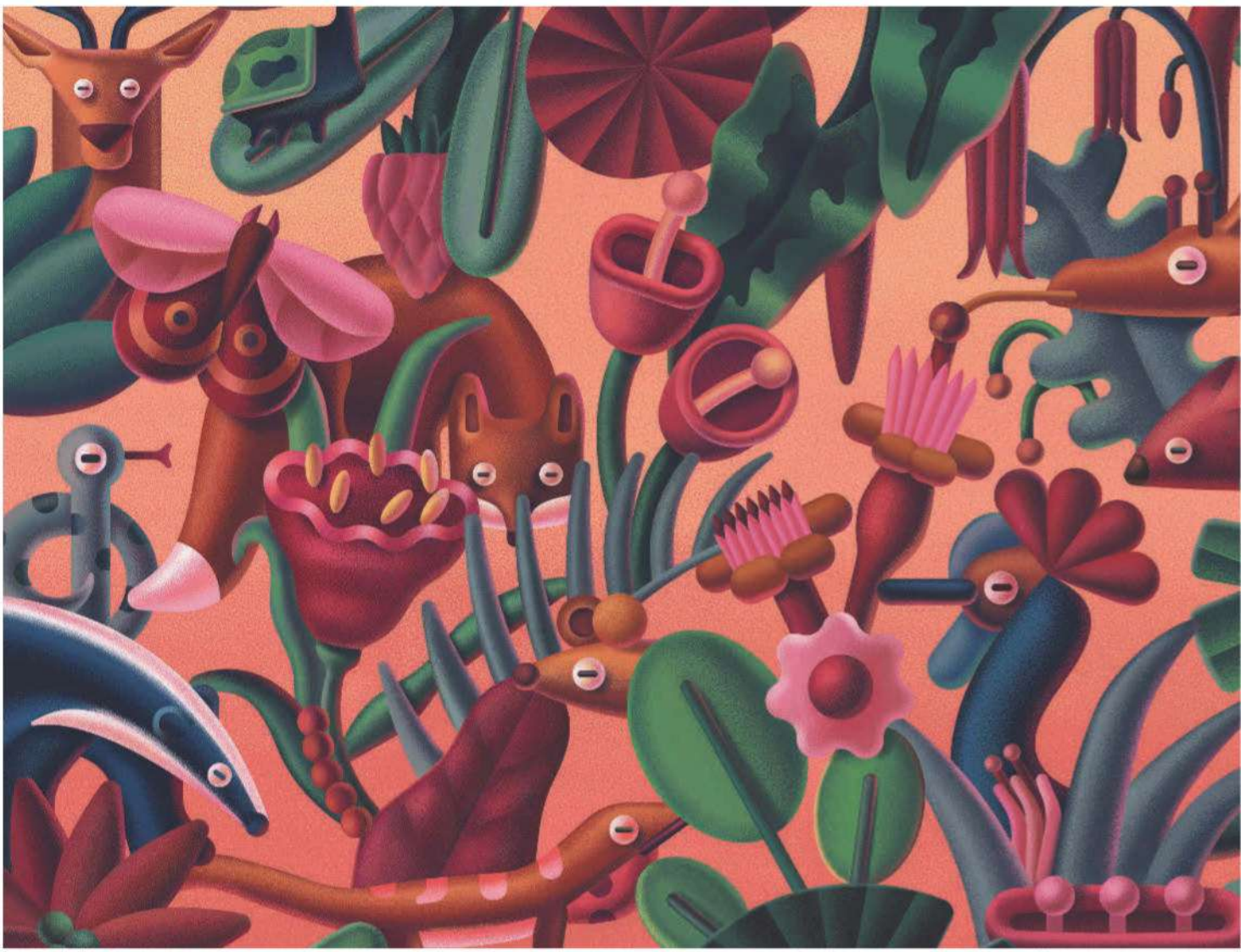

MARY MAKA

DIY evolution

Natural selection of random genetic mutation isn't the only way to adapt, argues evolutionary biologist **Kevin Lala**

LIVING in the desert is a challenge. But the Mojave desert woodrat has an ace to play: it can eat poison. This allows the cute little rodent to survive and thrive by feeding on toxic creosote bushes. Remarkably, it hasn't evolved the genes required to do so. Instead, it eats the faeces of other woodrats and thereby inherits detoxifying bacteria that take up residence in its gut.

The desert woodrat is an example of how the things organisms do can affect their evolution. And it is far from a one-off: in recent years, it has become clear that many organisms influence their own evolution by creating non-genetic traits that can become subject to natural selection. This challenges traditional Darwinian thinking, which sees evolution as a process rooted in random genetic mutation. But that's not all. These non-genetic ways of adapting may also help explain another puzzling aspect of evolution – evolvability, or why some organisms have a greater capacity to evolve than others.

I am one of a growing group of evolutionary biologists who believe that non-genetic inheritance plays a vital role in evolvability. This has practical implications. Faced with climate change, species must adapt fast or go extinct, and evidence is mounting that extragenetic adaptations, such as those found in the desert woodrat, can rescue organisms from the brink. The new thinking has implications for how we view our own evolution, too. Our complex culture makes the way humans evolve very different and far more rapid than the evolution of most other species. This unusual, supercharged evolvability gives us more control over our evolutionary future than we might think.

Historically, evolutionary biologists have assumed that since all organisms evolve through natural selection acting on their genes, they should all change at roughly the same rate per generation. Only in recent years has it become clear this isn't the case – some species and some traits are more evolvable than others. Until now, research has focused on genetic change, and genes undoubtedly are part of the explanation. But emerging evidence indicates that extragenetic processes are important, too.

This idea features in a new book that I co-authored – *Evolution Evolving: The developmental origins of adaptation and biodiversity*. A variety of processes are involved, but here I will focus on three of the most important and intriguing: epigenetics, symbiotic inheritance and culture. These phenomena aren't just analogous to biological evolution: they *are* biological evolution. They allow organisms to invade new environments, cope with change and stress, evolve new phenotypes and resist extinction until adaptive genetic mutations appear.

Consider, first, epigenetic inheritance. The DNA in each cell isn't bare, it is clothed in a variety of chemically attached molecules that affect whether or not nearby genes will be expressed. These modifications are epigenetic; they don't involve changes in the DNA sequence but nonetheless influence gene activity. The best-studied example is methylation, the addition of a methyl chemical group to one of DNA's nucleotide bases. This acts as a physical barrier, suppressing a gene's activity. Conversely, removal of the attachment allows a gene to be expressed. When a methyl group blocks the activity of a regulatory gene, the genes under its control can be expressed or suppressed more readily.

Some epigenetic attachments and detachments are specified by the DNA sequence itself, others occur at random, still others happen in response to environmental factors, including diet and pollution. When cells divide, these attachments are copied, which is what allows groups of cells, such as tissues, to maintain distinct patterns of gene expression from one another, even though they share the same DNA. In mammals, almost all epigenetic modifications are erased during the production of sex cells or in the embryo. In some animals, however, they are more commonly transmitted across generations. And in plants too, environmentally induced epigenetic changes are frequently inherited.

Adapt or die

Until recently, the idea that epigenetic variation is subject to natural selection was controversial. In 2018, publication of an experiment in thale cress (*Arabidopsis thaliana*) – the lab rat of plants – changed that. Marc Schmid, then at the University of Zurich, Switzerland, and his colleagues grew these plants in an environment that simulated a frequently disturbed, fragmented habitat and then selected only those that successfully dispersed to new locations, using these to form the next generation. Within just five generations, the population had evolved adaptations in flowering time and root density, but with no detectable change in gene frequencies. Instead, the adaptations had occurred through the natural selection of epigenetic variation.

Research published the following year backed up the idea that epigenetics can lead to adaptive evolution. Dragan Stajic, then at the Gulbenkian Institute of Science in Oeiras, Portugal, and his colleagues investigated the evolutionary adaptation of yeast to a toxic chemical. Their yeast populations were genetically identical but engineered to have different levels of epigenetic inheritance. The majority of those with low or no epigenetic inheritance went extinct, whereas other populations were able to survive and grow as a result of short-term adaptation through epigenetic change. This established an evolutionary beachhead, creating time for slower genetic adaptation to take its course.

This has implications for many organisms threatened by global warming. In the face of rapid environmental change, strong ›

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Orca evolution is driven partly by culture, such as hunting behaviour

selection can erode a population's genetic variation, making evolutionary rescue through genetics even more unlikely. But epigenetic adaptation creates variation in characteristics, increasing the likelihood that some fraction of the population will persist long enough to adapt genetically. What's more, the fact that some epigenetic variation is environmentally induced means that, unlike genetic mutation, it can appear suddenly in multiple individuals. This makes potentially adaptive variants less vulnerable to loss through random processes. In this way, epigenetics can buffer a population against extinction.

Let's turn now to symbiotic inheritance. The burgeoning interest in microbiomes has made it clear that animals are teeming with microbes. Such symbiotic relationships are common throughout nature, and the Mojave desert woodrat provides a clear example of how they can influence evolvability.

One thing that makes symbiotic inheritance so powerful is that it needn't be passed from parent to offspring – it can spread among unrelated individuals and even occur across species. For example, plants that grow on geothermal soils are commonly associated with a heat-tolerant mould called *Curvularia*, and experiments show that exposure to this mould increases the survival of other species of plants when they are subjected to heat stress. Similarly, salt-tolerant fungi can enter symbiotic relationships that help non-adapted plants survive salty conditions. More problematically – at least from a human perspective – various insects have acquired pesticide resistance from a pesticide-degrading bacterium. And the red turpentine beetle recently became a pest when it acquired a fungal symbiont that allowed it to infest live trees. Millions of trees in China have perished as a consequence.

"From the origin of life, organisms channelled and directed their own evolution"

Dogs have also benefited from symbiotic inheritance. Their wild ancestors were carnivores, but during the course of domestication, dogs adapted to eat a more starchy diet associated with farming. Today, like us, they have extra copies of two genes, *AMY1* and *AMY2*, that aid in the digestion of starch by producing enzymes secreted in saliva and the pancreas. Ancient DNA extracted from 3500-year-old fossil dogs and their faeces, however, reveals that while these animals lacked this genetic adaptation, they did possess symbiotic bacteria that broke down starch in their bodies. Seemingly, dogs adapted to their novel diet in two stages, first through bacterial symbionts, and only thousands of years later through genetic change.

Other examples of symbiotic inheritance are found in humans. Japanese people, but not Westerners, can digest the jelly-like substance agar because they have a bacterium in their gut that contains a gene coding for the enzyme agarase. They are thought to have acquired this bacterium through eating seaweed. Similarly, some human populations can digest dairy products despite lacking the gene variant for adult lactose absorption that emerged among dairy farmers around 7000 years ago. In this case, their agricultural activities have exposed them to bacteria that do the job when ingested. Indeed, the human appendix is testament to the vital role that symbionts play in our survival. Long regarded as a vestigial organ with no current function, it is now thought to act as a repository for beneficial gut microbes

Enhanced adaptability

An organism's capacity to evolve, known as evolvability, can be influenced by non-genetic phenomena such as symbioses and culture (see main story). But they aren't the only non-genetic ways to be adaptable.

Developmental plasticity, for example, is a kind of variation caused by environmental factors influencing the way that an organism develops. Although initially there is no change in the genes, plasticity can increase the ability to evolve.

Take the Mexican blind cavefish (pictured below). At least 30 cavefish populations are known, mostly eyeless and with reduced pigmentation, and sometimes also with characteristic bone structure, fat storage and foraging behaviour. Other populations of these fish live in rivers and lack these traits. But, when reared in the dark, they come to resemble their cave-dwelling cousins because developmental plasticity allows these same traits to emerge.

Such plasticity doesn't just help organisms cope with novel challenges, it also helps them evolve by packaging together a suite of adaptive traits. Natural selection can only work with the available variation, so evolution becomes channelled along these self-generated axes of linked traits.

Another way organisms can increase their evolvability is by modifying their environment, a process known as niche construction. By building a nest or burrow, for example, animals control key aspects of their environment, such as temperature. If their offspring's development is sensitive to these conditions, plastic traits can coevolve with the niche-constructing traits. And because niche construction tends to link adaptive traits together, it too influences both evolvability and the direction of evolution.

BARRY MANSELL/NATUREPL.COM

that can recolonise the intestine after bouts of stomach disease and infection.

What really makes us so extraordinarily adaptable, however, is culture. It is well-established that human culture can generate complex adaptations that are subject to selection – a classic example being the aforementioned evolution of agriculture. But things get more interesting with the recognition that many other animals have culture too. In fact, in the past half century, scientific investigations have shown it to be surprisingly common. Countless species transmit learned knowledge from one group member to another and down the generations through imitation and other forms of social learning. Such cultural inheritance includes dietary information, feeding techniques, songs and calls, predator recognition and avoidance methods, and learned migratory pathways.

Highly cultured animals

The influence of culture on evolution is seen clearly in killer whales. Some populations of orcas have learned to make waves to dislodge seals from ice floes, others lunge onto beaches to pick off prey. These adaptive differences in diet and hunting technique aren't due to genetic variation, they are the product of behavioural innovation and social learning. Nonetheless, such cultural differences in hunting have biological impacts. Despite often living side by side, groups of whales with different foraging habits are reproductively isolated. As a result, they have diverged genetically and exhibit morphological and physiological adaptations such as population-specific digestive enzymes and face shape.

Like epigenetic adaptation, cultural adaptation has important implications for evolutionary rescue from extinction because culture can change more rapidly than genes. This is relevant to conservation strategies because it implies that the first response of many endangered animals is likely to be cultural rather than genetic. It also means that animals with culture may have a greater capacity to adapt to climate change.

The upshot of all this is that natural selection isn't something that just happens to organisms: their activities and behaviours contribute to how it happens and whether it happens at all. Culture, symbiosis and epigenetics all promote evolvability, and they aren't the only extragenetic mechanisms at play (see "Enhanced adaptability", left). That means a conception of how organisms work should be central to our understanding of evolution. This adds a whole new dimension to the evolutionary process because the things organisms do that influence their evolution have themselves evolved through natural selection – making the Darwinian evolutionary algorithm cyclical. From the origin of life, through continual interactive cycles of causation, organisms have channelled and directed their own evolution, and evolution has sculpted them in turn.

This new perspective on evolvability has big implications for how we regard our own evolution. Historically – perhaps to distance themselves from creationists and mystics – evolutionary biologists have maintained that humans evolve in a manner no different from fruit flies or yeast, that it all comes down to the natural selection of chance mutations. This simple, bleak story lacks credence to some people, which might help explain why there is resistance to evolutionary theory. Instead, in the light of these new findings, we should be emphasising that human evolution is actually very unusual, because evolvability depends on what organisms do, and our activities are quite distinct from those of other species.

Human culture is off the scale compared with any other animal when it comes to symbolism, technology and informational content. The significance of this becomes clear once we recognise cultural change for what it really is – not so much an analogue of biological evolution, but rather a key aspect of rapid-response evolutionary adaptation. This means that we are far more evolvable than most other species – and we control our own evolution to a much greater extent. But our choices don't just affect us, they have wide-reaching impacts across the environment. This gives us enormous power over the future evolution of all life on Earth – for good or ill. ▮

Kevin Laland is a behavioural and evolutionary biology professor at the University of St Andrews, UK. His new book *Evolution Evolving* is out now

Dripping with promise

RYAN PIERSE/GETTY IMAGES

Monitoring your sweat could reveal incredibly useful insights into the state of your health, finds **Graham Lawton**

"WOW, you're quite salty," says Stefan van der Fluit, looking over my numbers. I could have told him that. I have just done a sweaty, 45-minute workout on an exercise bike and the salt is already starting to crystallise on my T-shirt. But van der Fluit knows exactly how salty. I have just sweated out 347 milligrams of sodium in 370 millilitres of water. That's on the high side, sodium-wise, and I need to replenish.

Van der Fluit is the co-founder of a company called Flowbio, based in London, which specialises in sweat analysis for athletes. During my workout, I was wearing a sensor called the S1 on my upper arm, which collects sweat in a tiny channel, automatically measures its volume and sodium concentration, and transmits the data to a smartphone app. Using that data, the app calculates my total losses.

If I were an endurance athlete, that data would be extremely valuable, perhaps the difference between winning and losing. I'm not, but van der Fluit is. As a competitive cyclist, he has had long-standing problems with dehydration. But since he started using the sweat sensor, they have gone away, and his performance has improved.

Flowbio's S1 is one of a handful of wearable sweat sensors that have come onto the market in the past few years. They are mainly aimed at people who sweat a lot in the course of their jobs – athletes and manual workers – but they are also available to the general public, and, in the not-too-distant future, similar devices could be collecting all manner of health-related information from regular Joes like me.

Although sweat is mostly water and salt, it is also dripping with biomolecules that can provide all sorts of useful insights about what is going on inside our bodies. "Sweat is data," says Flowbio's head of research and development, Roeland Mingels. And now the race is well under way to put that data to good use.

Sweat has long been recognised as a marker of health. For centuries, it was noted that children with especially salty sweat failed to thrive. In the 17th century, this was blamed on bewitchment, but it is now known to be a symptom of the congenital condition cystic fibrosis. In the Middle Ages, a mysterious illness called sudor anglicus (sudor is Latin for sweat) struck England. The main symptom was profuse sweating, closely followed by death. We sweat when feverish, and night sweats can be an indicator of serious underlying health problems, including cancer, autoimmune disease, brain injury and hormonal disturbances.

Complications with the sweating system can also be problematic. Excessive sweating, or hyperhidrosis, can cause dehydration and skin problems and can be socially embarrassing. The opposite, hypohidrosis, where people sweat very little, or even anhidrosis, in which people can't sweat at all, can cause heat stroke – a potentially life-threatening condition.

Anhidrosis notwithstanding, sweating is a fact of life. Most of us have between 2 million and 4 million functioning sweat glands all over our skin that leak constantly, a process called insensible sweating because we don't notice it. But when our internal thermostat rises, either as a result of an increase in ambient temperature or due to heat generated by exercise, those glands put their hands to the pump and the sweat really starts to flow.

The function of this "eccrine" sweat is evaporative cooling, which keeps our body temperature from rising too high. But because sweat is derived from blood plasma and the interstitial fluid between cells, molecules dissolved in these also leak into sweat. The main non-watery components of sweat are electrolytes – sodium, potassium and chloride ions – but these are the tip of the sweatberg.

All told, more than 30,000 biomolecules have been detected in sweat, ranging from metabolites such as glucose and lactic acid to peptides, proteins, vitamins, inflammatory molecules, hormones and neurotransmitters. Substances we put into our bodies, such as pharmaceuticals and recreational and performance-enhancing drugs, also find their way into sweat. So do environmental pollutants such as heavy metals and chemicals found in plastics.

That presents a juicy opportunity. Because sweat reflects what is going on inside our bodies, it could be used as a "diagnostic biofluid", says John Rogers at Northwestern University in Evanston, Illinois.

There are other such fluids, of course – blood, urine and interstitial fluid are routinely sampled and analysed to provide biological insights. But they have drawbacks. All three generally require a trip to a clinic followed by laboratory analysis, and collecting blood and interstitial fluid is invasive. Blood and urine samples provide detailed snapshots, but cannot be used for continuous monitoring, ›

"The idea of using sweat to get a deeper understanding of our health is going to be groundbreaking"

which for certain compounds, such as glucose, is more useful. And while interstitial fluid can solve that problem, wearable monitors still have to penetrate the skin with a thin electrode. "I think for routine use, one has legitimate concerns around risks for pain and infection and dislodgement and other sorts of complications," says Rogers.

These drawbacks led to a search for biofluids that can be sampled continuously and non-invasively. Tears, saliva and breath condensates have all been tried, but sweat trumps them all, he says.

You don't even have to overheat or exercise to produce the stuff. A well-established procedure called iontophoresis, in which a sweat-inducing drug such as carbachol is applied to the skin along with a weak electrical current, reliably stimulates the sweat glands for extended periods. "This allows us to sample sweat at any given time," says Wei Gao at the California Institute of Technology in Pasadena.

Over the past decade or so, this combination of accessibility and continuity has led to a wealth of research on the contents of sweat. "There are a lot of clinically relevant biomarkers in our sweat," says Gao. "We could use this information for health monitoring, disease diagnosis and, importantly, this will give us early warning before we develop more severe health conditions."

The diagnostic potential of sweat has been recognised since the early 20th century, when biochemists discovered that it is more than just salty water. Until now, however, sweat analysis has found only two medical uses, according to Jason Heikenfeld at the University of Cincinnati, Ohio. One is to diagnose cystic fibrosis in newborns and young children via high levels of chloride ions in their sweat, a result of the genetic change that causes the condition. The other is to map nerve damage, which can stop sweat glands from functioning.

The modest impact is partly because of historical difficulties in sampling and analysing sweat. Even though it can be collected on demand, quantities are limited and the concentrations of the molecules of interest can be vanishingly small. The 370 millilitres of water and 347 milligrams of sodium I sweated out at Flowbio is an extrapolation of my whole body's output; the sensor itself gathered a fraction of 1 per cent of that over 45 minutes of prolific perspiration. The cystic fibrosis test, developed in the 1950s, requires the collection of a large amount of sweat through iontophoresis followed by laboratory analysis.

DAVID DEE DELGADO/AFP VIA GETTY IMAGES

Sweat sensors can help athletes stay well-hydrated

But in the past decade or so, advances in microfluidics, materials science, diagnostics, batteries and data transmission have made real-time sweat analysis possible using wearable patches. Such wearables have transformed the prospects for sweat diagnostics, says Rogers.

The first applications to make good on that promise are sensors like Flowbio's, which gather the low-hanging fruit of water and electrolytes. Three other companies have similar sensors on the market aimed at athletes and gym fanatics, to inform them about their rehydration needs during and after a workout.

One of the companies is Epicore Biosystems of Cambridge, Massachusetts, which Rogers co-founded. In 2021, it released a product called the Gx Sweat Patch in partnership with design company Smart Design and the sports drinks company Gatorade. It is a flexible, disposable, stick-on wearable that is attached to the upper arm before a workout.

The patch has two microfluidic channels that gradually fill with sweat. One measures the overall volume and the other the concentration of electrolytes using a colour-changing dye. To get their results, users photograph the patch at the end of their session and send the image to Epicore, which calculates whole-body losses and recommends which electrolyte-filled Gatorade product to drink and in what quantity in order to rehydrate. Around 3 million of these patches have been sold, according to Rogers.

Epicore has since rolled out a similar product, Connected Hydration, which is designed to protect workers in physically draining industries such as oil and gas, mining and agriculture. Dehydration and heat exhaustion are a growing problem for such industries as the climate warms, says Epicore CEO Roozbeh Ghaffari, and companies increasingly recognise the danger – not least to themselves, as the cost of insuring against heat-related industrial injuries is skyrocketing.

Connected Hydration transmits real-time data via Bluetooth and a smartphone to

"A non-invasive anti-doping tool offers a lot of promise"

employers, who can warn workers of dehydration or heat exhaustion. When employees have lost 2 per cent of their body weight in sweat – a validated point at which dehydration affects physical and cognitive performance – the device vibrates, prompting them to take on fluid and electrolytes. "It hits the nail well, to provide a novel solution for a major public health threat," says Noé Brasier at ETH Zurich in Switzerland.

Analysing sweat loss, sweat rate and electrolyte loss is relatively simple, but it is just the first block of what Rogers and his colleagues ultimately hope to build into a mighty edifice of diagnostic tools.

The first step for Rogers is adding a pH monitor to his company's sweat patches. Since pH is affected by lactic acid buildup in the muscles, which increases as you work out, it acts a useful proxy for exercise intensity.

Beyond water, salt and pH lies a largely unexplored ocean of biological information with many potential applications. Earlier this year, Epicore teamed up with the US Anti-Doping Agency to develop a patch to detect performance-enhancing drugs in sweat. "As an athlete, anti-doping sucks," says Ghaffari. "Nobody likes urine, nobody likes blood. A lot of athletes are afraid of needles. So, a potential non-invasive tool offers a lot of promise."

Sweat analysis could also be used to monitor recreational drugs in people who are in recovery or who are required to abstain as a condition of their bail. Most of the major ones – alcohol, opioids, cocaine, amphetamines and cannabis – come out in sweat and can be detected, says Brasier.

The microfluidic pipeline is rich with other potential applications. For instance, in collaboration with the University of California, Los Angeles, Gao is planning a clinical trial of an early-warning system for gout, an agonising type of arthritis caused by excessive levels of uric acid in the bloodstream. Uric acid levels in sweat closely mirror those in the blood, so a wearable sweat patch could alert users to an impending flare-up, allowing them to adjust their drugs or change their diet to avoid it.

High uric acid levels are also a risk factor for cardiovascular disease, diabetes and kidney disease, making monitoring even more valuable. Similarly, monitoring of the inflammatory molecule C-reactive protein could provide useful information on a range of inflammatory conditions.

Conception cues

Gao's work even extends to our hormonal system. Working with NASA and the US military, he is developing a sweat patch that monitors cortisol, a hormone associated with stress. Likewise, he has his sights set on monitoring the female reproductive hormone oestrogen, which surges just before ovulation and can be used as a cue to attempt conception (or avoid it).

"There are large gaps in scientific knowledge about the role of sex hormones in women's health," says Pauline Maki at the University of Illinois College of Medicine, who has consulted for Gao's spin-off company Persperity. "These hormones fluctuate naturally on a day-to-day basis in younger women, and current methods require a blood draw to quantify these fluctuations. The new sweat-based technology provides a highly innovative method for quantifying these fluctuations without the burden of a blood draw and a lab visit. Moreover, the sensors can measure other biomarkers, such as those associated with pain or mood."

DAVID STOCK

Graham Lawton's sweaty workout provides useful health insights

The list of potential uses goes on – other groups are investigating using sweat to monitor everything from heart failure to circadian rhythms and biological age. "I think we're going to establish a pretty powerful pipeline of applications that will be commercialised over time," says Rogers.

Nevertheless, sweat does have its limitations. Though the concentrations of many of the compounds it contains correlate nicely with those in blood, many others don't – glucose, for instance – so they cannot be used as a proxy. Heikenfeld also cautions that sweat biosensing is likely to be far more complex than the sensing involved in any other commercial wearable device. As a result, monitoring interstitial fluid may be more popular, despite its invasiveness, he says.

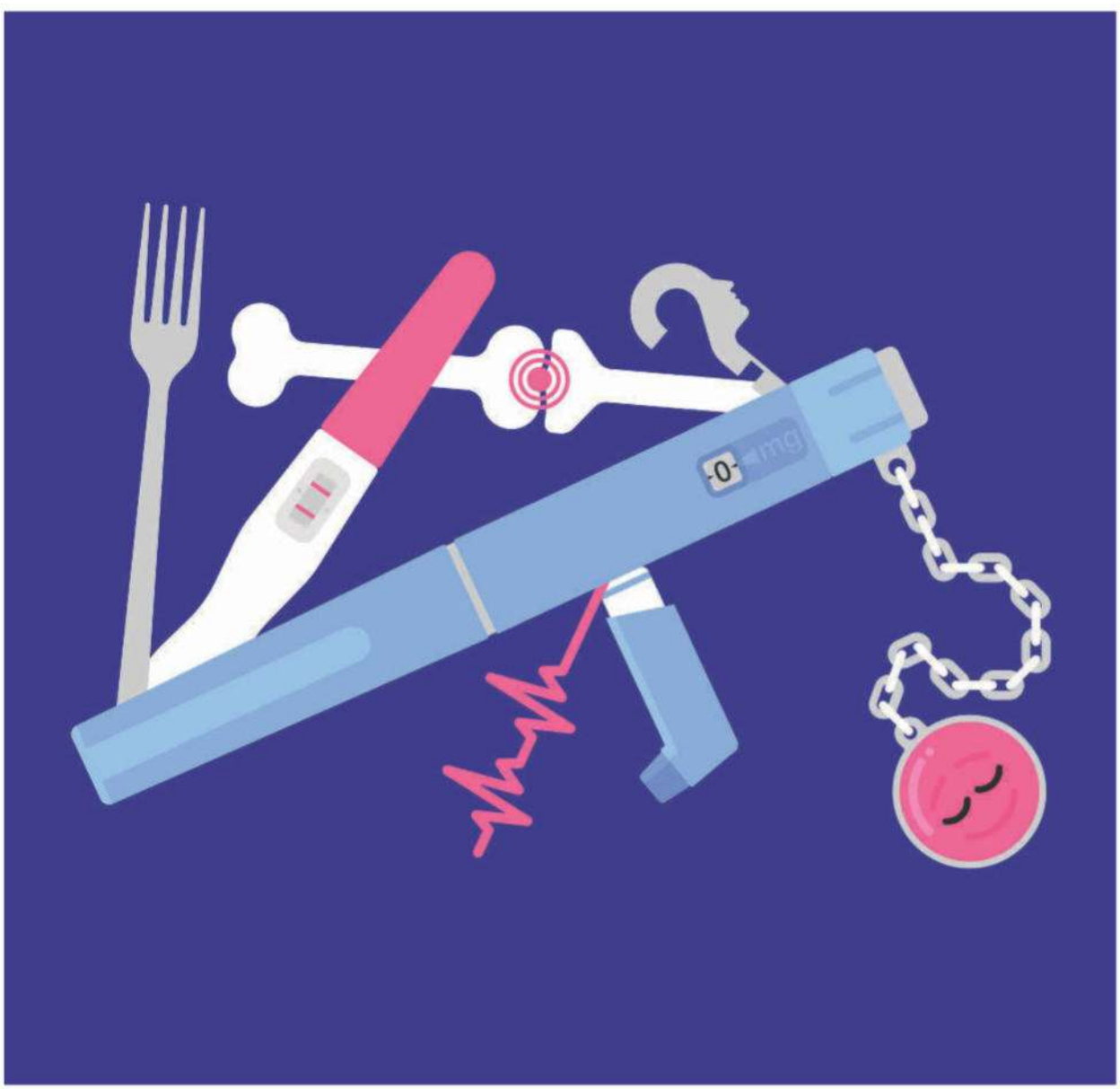
Nonetheless, Heikenfeld believes that sweat is better than other non-invasive biofluids, and that the challenges of collecting and analysing it can be overcome.

That means perspiration pioneers aren't sweating just yet. "I think the idea of sweat sensing to get a deeper understanding of our biomolecular health is going to be quite groundbreaking," says van der Fluit. Success, after all, is 1 per cent inspiration, 99 per cent perspiration. ▮

Graham Lawton is a staff writer at *New Scientist*

THE EVERYTHING DRUG

From Alzheimer's and heart disease to depression and fertility, weight-loss drugs like Wegovy seem to have wide-reaching effects. But how do they actually work? **Helen Thomson** investigates



PÄYÉ

IT IS rare that a drug becomes a household name and even rarer for one to become a superstar, but with its ability to grab headlines, Ozempic is the Taylor Swift of pharmaceuticals. So just what lies behind its star power? Even as the drug and its derivatives take off, researchers are racing to find out how it works.

"We're seeing so many incredible benefits," says Steven Dayan at the University of Illinois. "It's early days, but it's looking like these drugs aren't just going to change medicine but our whole economy."

Most medicines only treat one or two conditions, meaning that "cure-alls" promising to tackle any and all ailments are usually viewed with scepticism and suspicion. Ozempic seems to buck that trend. Last year, Wegovy – a version of Ozempic approved for weight loss – was shown to reduce the risk of heart attack and stroke by almost 20 per cent. The emergence of "Ozempic pregnancies" hinted at fertility benefits. People started noticing positive effects on depression and anxiety. In May, results showed it also slashed the risk of kidney failure and death in people with diabetes during a three-year trial. In July, another version of the drug was found to reduce brain shrinkage and slow cognitive decline in people with Alzheimer's disease.

Why this drug is helping so many conditions is still mysterious, but researchers are beginning to unravel the mechanisms underlying its extraordinary abilities. From its effects on reward circuits in the brain to its impact on inflammation, understanding these pathways should reveal the full spectrum of health issues it could address – and where we might fall foul of unintended consequences.

The Ozempic story begins in the 1980s, with the discovery of the hormone glucagon-like peptide-1 (GLP-1). This helps lower blood glucose levels, which can get dangerously high in people with diabetes, so the thinking was that a drug that mimics GLP-1 could help treat the condition.

Drug company Novo Nordisk's first such medicine, liraglutide (sold as Victoza), was approved by the US Food and Drug Administration in 2010. It reduced blood glucose but had to be injected daily. The real breakthrough came in 2017, when Novo Nordisk introduced a longer-lasting GLP-1 drug – semaglutide – which it marketed as Ozempic. Initially approved as a weekly injection for type 2 diabetes, it produced notable weight loss, leading to the creation in 2021 of Wegovy, a higher dose version approved as a treatment for obesity. This helped people typically lose around 15 per cent of their weight after one year of taking the drug. Despite its high cost – up to about $1300 a month – it has been wildly successful, with around 25,000 people starting to use the drug each week in the US.

GLP-1 is released by the intestine, pancreas and brain after we eat, so it is perhaps no surprise that semaglutide modifies our eating behaviour. The hormone signals to the pancreas to release insulin, which lowers blood sugar. It slows the passage of food through the stomach, which keeps you feeling fuller for longer, and acts on brain areas responsible for motivation and reward processing, all of which curb your appetite. Research also suggests that it may modify gut flora, encouraging a balance of bacteria that promotes a healthier metabolism.

"These drugs aren't just going to change medicine but our whole economy"

Weight loss from taking semaglutide also explains some of the other health benefits we are seeing, such as boosts in fertility. "There isn't an organ in the body that isn't improved by losing a little weight if you have a high body mass index," says Randy Seeley at the University of Michigan in Ann Arbor.

Beyond slimming

But it isn't the whole story. Take the discovery that semaglutide improves heart health, for instance. A study of more than 17,000 people with cardiovascular disease showed that the drug significantly reduced the risk of death from heart disease or stroke. A lower weight reduces cholesterol, which blocks arteries among other things, yet slimming down isn't the dominant factor. "People are seeing benefits to their cardiac health independent of the amount of weight they have lost by taking the drug," says Seeley.

This is where another effect of semaglutide comes into play: it acts as an anti-inflammatory. It does this through various mechanisms, including modulating how cells signal to the immune system, decreasing the release of pro-inflammatory chemical messengers called cytokines and switching off genes responsible for the immune response. Chronic inflammation, which can compromise the immune system and cause arteries to harden, is increasingly being linked to a huge number of conditions, making it an ideal target for treating more than just heart disease.

In fact, semaglutide and similar drugs called GLP-1 agonists have been shown to improve many conditions that involve inflammation, such as asthma, non-alcoholic fatty liver ›

disease, arthritis and psoriasis. They are also showing promise for treating sepsis, as well as infections that create "inflammatory storms", like covid-19. "What we have is this Goldilocks effect," says Seeley. "GLP-1 agonists reduce inflammation, but not so much that you put people at risk of infection and cancers – it's vital we find out more about why."

Given the importance of inflammation in so many conditions, you might wonder why we are only just discovering the anti-inflammatory potential of GLP-1 agonists. Seeley says it just wasn't on people's radar. "Remember, these drugs were never designed to be anti-inflammatories, immunologists weren't doing the early research," he says. "They were discovered by endocrinologists for glucose control. There's a lot of serendipity at work."

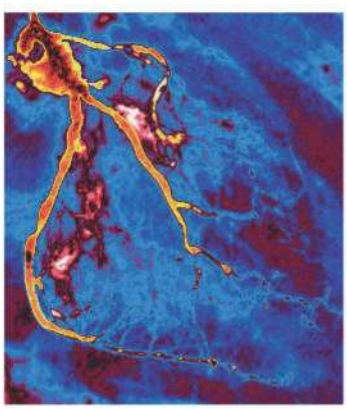
Another factor is that compared with insulin, which has almost a sledgehammer effect in the body – lowering blood glucose levels dramatically – GLP-1 agonists have a much more nuanced effect, which, had their wider benefits not become apparent in those taking them for diabetes or weight loss, immunologists might have found too subtle to spot.

Along with their anti-inflammatory properties, GLP-1 agonists also slow the death of nerve cells – two attributes that might help with Alzheimer's. Could the drugs offer a treatment? Perhaps. When Paul Edison at Imperial College London and his colleagues treated people with Alzheimer's using liraglutide, they found it reduced brain shrinkage by 50 per cent and reduced the rate of cognitive decline by 18 per cent compared with a placebo after one year of treatment. The work was presented at the Alzheimer's Association International Conference in Philadelphia, Pennsylvania, in July. In October, there was more good news: a study of 1 million people in the US with diabetes but no prior Alzheimer's diagnosis showed that taking semaglutide was associated with a 70 per cent lower risk of being diagnosed with the condition compared with taking insulin.

It isn't clear what pathways the drug is targeting, but it is likely to be more than one, says Edison. "In my view, there are a lot of independent processes involved in the pathology of Alzheimer's, so a drug that has a multipronged attack is well suited to treating the disease." A spokesperson for Novo Nordisk

RICHARD LEVINE/ALAMY

Weight-loss drugs such as Wegovy (below) are widely and prominently advertised in the US (left). These drugs may target conditions that affect the coronary arteries (below left)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MICHAEL SILUK/UCG/UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

"What we have is a Goldilocks effect. These drugs reduce inflammation, but not too much"

COLDSNOWSTORM/GETTY IMAGES

Drugs such as Ozempic may help reduce how much people think about food

says it is evaluating an oral version of semaglutide for the treatment of early Alzheimer's disease in a trial of around 1800 people.

Neuroscientists are waking up to the huge potential for weight-loss drugs to alter the brain in other ways too. Many people taking Wegovy have reported reduced cravings not only for food, but also for alcohol, cigarettes, shopping and even nail-biting. If true, this phenomenon could have major implications for treating addictions. In October, a study of more than half a million people with a history of opioid use disorder showed that those who took Ozempic or similar GLP-1 agonists had significantly lower rates of opioid overdose than those who didn't take these medications.

Some researchers believe that by targeting areas of the brain responsible for reward signals from food and reducing the motivation to eat, GLP-1 agonists also lessen the reward people get from addictive substances and the motivation to take them. Trials are now running to see if these medicines can help people quit alcohol, smoking and other drugs.

But there may be a downside. A study presented in October at the Society for Neuroscience conference in Chicago showed that mice given semaglutide were less motivated to exercise – with the implication being that dampening reward circuits might make positive behaviours like exercise less rewarding too.

Seeley, however, considers this an oversimplification. "The idea that you can clump all these rewarding behaviours together in the brain so that when you reduce reward from one you reduce reward from them all, just doesn't make sense," he says. "The brain is more nuanced than that."

Indeed, GLP-1 receptors are scattered all over the brain, which could explain some of the effects we are seeing on people's mental states. Early this year, an analysis of more than 4 million people linked GLP-1 agonists with lower rates of anxiety or depression. This may be partly thanks to the loss of weight – there is a well-established link between obesity and mood disorders.

Rachel Goldberg, a private psychotherapist in Los Angeles, says she tends to observe her clients feeling more positive and joyful after taking these weight-loss drugs. "I believe this is often because, without the 'food noise' that many struggle with, they have more mental space to enjoy other aspects of life," she says.

"Without 'food noise', people have more mental space to enjoy other aspects of life"

"Feeling more in control of food choices or behaviours can relieve stress, improving some people's emotional balance," says Pamela Tambini, a physician in Florida. But studies indicate that something more complex is going on. A trial of liraglutide in 19 people with major depressive disorder or bipolar disorder suggested it improved mood, attention span and cognitive function, irrespective of whether they lost weight.

The trial found that the drug increased the volume of brain areas involved in planning, organisation and emotional processing, which may be why it helps people regulate their mood. "GLP-1 receptors may impact mood-regulating neurotransmitters like dopamine and serotonin, which play key roles in emotional responses," says Tambini. The GLP-1 hormone also appears to affect how easily glucose is transported into the energy-hungry brain and the rate at which it consumes glucose, which may be why it boosts the brain's ability to operate.

Such questions about glucose levels take us back to where we started, when the hormone and its impact on glucose was first discovered. Now that we can add everything from reward mechanisms to anti-inflammation to the list of its functions, understanding how all of these effects interact and overlap is going to take time – even if many people don't want to wait.

Ozempic face

"There's some level at which, as a physician, you don't care how it's working as long as it is working and it's safe," says Seeley. "Understanding the mechanisms behind all these things is going to take a while to figure out."

Beyond scientific curiosity, a deep dive into the mechanisms of this wonder drug could also help us tackle big unanswered questions. For one, semaglutide isn't without side effects, such as constipation, muscle wasting and a newly discovered problem labelled Ozempic face, where facial ageing appears accelerated compared with that in people who lose weight without the drug. This seems to originate from a loss of fatty tissue and the altered growth of stem cells derived from this tissue, which are involved in the production of certain hormones and metabolites. Together these compromise the structural integrity of the skin, says Dayan. This is primarily a cosmetic issue, he says, but more research is needed to understand the exact consequences that skin changes might have on wider health.

Another big question is one being voiced by many people excited by semaglutide's widespread effects: could everyone benefit from it in some way? "I find myself thinking 'should I be taking this in a microdose?'" says Dayan.

It isn't the first time we have thought this about a drug. Some live up to their promise: aspirin was originally developed to reduce fever but then showed beneficial effects in reducing pain and preventing cardiovascular disease. Today there is growing evidence that, in low doses, it also helps to prevent some types of cancer. But it doesn't always work out like this. "When statins were discovered, we went through the same thing. People were saying 'it's so good should we just put this in the water'? But it turned out it didn't do everything we hoped," says Seeley.

We are now at the point of maximum enthusiasm, asking whether semaglutide can help cure cancer, treat Alzheimer's, reverse arthritis and more. "We are in the 'maybe it will cure everything' stage with this drug," says Seeley. "Some of these ideas are going to fall by the wayside when we do good trials, some will work out, but there's a lot of work to be done before we understand what these drugs are truly capable of." ▮

Helen Thomson is a journalist based in London

Alien plate tectonics

Plate tectonics may be key to the origin and survival of life on Earth – but do any other planets undergo this crucial process, asks **Elise Cutts**

MARK GARLICK/SCIENCE PHOTO LIBRARY/ALAMY

THERE is something strange about Earth. A few billion years ago, a process started here that we have never seen anywhere else. It completely reshaped the planet's surface and its carbon cycle, sculpted new landscapes and has kept our home temperate and habitable for billions of years.

That process is plate tectonics, in which Earth continuously subsumes and reforms the slabs of its rocky outer shell. It is thought to be inextricably linked to habitability and perhaps an essential prerequisite for life itself. Without it, our lakes and rivers might have frozen or evaporated, the oceans could have been starved of nutrients and Earth's climate would probably have veered into unlivable territory long ago. Life would have been in for a rough ride.

At least, that's the idea. But it is tough to know whether plate tectonics is really crucial to Earth's verdant ecology, given that we have nothing to compare it with. We know of no other planet that exhibits plate tectonics: among the four rocky planets in our solar system, Earth is the only one to recycle its crust in this way, and we haven't spotted definitive signs of it beyond our solar system either.

Until recently, this was more or less where the story ended. But now, with the help of the James Webb Space Telescope (JWST), scientists are beginning to explore the geology of rocky worlds beyond our solar system. Finding one with plate tectonics will be a huge ask. But if we succeed, it could be the key to figuring out how life began here on Earth – and where to search for it out in the cosmos.

While it might be feasible for life on another world to get by without plate tectonics, "we do know that on Earth, it definitely made it more likely that life could develop", says Tobias Meier at the University of Oxford. If Earth is a spaceship, plate tectonics is its life-support system: a recycling process and thermostat in one. It describes how our planet's rocky outer skin is fractured into a jigsaw of shards – tectonic plates – that drift about over the gooey, molasses-like mantle. In areas where hot material from the mantle wells upwards and the plates pull apart, lava spews forth from volcanoes along the rift, forming new land. When plates crash together, one can end up slipping below the other, driving cool, dense material into the mantle.

Ocean life depends on nutrients that erode out of the continents and terrestrial life, in turn, depends on the fertility of the oceans. But without plate tectonics to build continental crust and constantly thrust up fresh mountain ranges, some scientists think erosion would slow as the land got flatter and flatter, starving the oceans of key nutrients.

Then again, without plate tectonics we might not have liquid water at all. It controls Earth's "natural thermostat", the carbonate-silicate cycle, which acts over millions of years to keep the planet's temperature in check. In this cycle, atmospheric carbon dioxide reacts with water and freshly exposed rocks and is eventually swallowed into the planet's mantle through plate tectonics, before being belched up again by volcanoes. It is crucial for regulating the amount of CO_2 in the atmosphere and thus the temperature of our planet.

The carbonate-silicate cycle has been Earth's saving grace in the past. It is believed to have rescued the planet from climate catastrophe over the aeons, including at least two "Snowball Earth" episodes, in which the entire world froze over, and multiple hothouse periods that killed off nearly all life. If human-caused climate change culminates in disaster, it could be this cycle that, over millions of years, allows our planet to heal.

Distant worlds

Perhaps other, more distant worlds have similar life-support systems – and now, the door to studying geologic processes such as plate tectonics on exoplanets is creaking open. Over the past two years, for example, JWST has begun revealing a small handful of rocky worlds in unprecedented detail.

Realistically, we are probably still a very long way from discovering plate tectonics on another world, just as we are far away from detecting a definitive signature of alien life. But thanks to new data and techniques, scientists are taking their first bold steps into an entirely new frontier: exoplanet geology.

If we want to find plate tectonics – or at least a strange alien equivalent – we will have to look beyond our solar system. The first planet to reveal its tectonic character just might be a world called LHS 3844 b, which orbits a small, dim star about 49 light years away. "I'm just really excited," says Sebastian Zieba at the Harvard-Smithsonian Center for Astrophysics in Massachusetts, who is leading an effort to examine the exoplanet's rocky surface. "It's really cool that this actually ›

NASA

RON MILLER/SCIENCE PHOTO LIBRARY

Other worlds with intense volcanic activity could be the best places to look for tectonics

works, especially because these planets are so far away."

Discovered in 2018, LHS 3844 b is a rocky world a bit bigger than Earth that clings so closely to its star that its years last only 12 hours. This tight orbit has also led the planet to become tidally locked: one hemisphere always faces the sun while the other never sees daylight, resulting in a temperature difference between the day side and night side of about 770°C (1418°F). It is hard to imagine a more alien place. But planets like this seem to be quite common in our galaxy, says Meier. And unlike worlds reminiscent of Earth, orbiting sun-like stars, these kinds of "ultra-short-period" exoplanets – worlds with zippy orbits – are ideal targets for JWST because of their relative brightness and how frequently they can be observed passing in front of their stars.

"So, I'm really interested in figuring out: could they have plate tectonics? Or what kind of tectonic regime could they be in?" says Meier. In 2021, he and his team used computer models based on observations to show that LHS 3844 b could sport a new kind of alien tectonics driven by the enormous temperature contrast between the day and night sides of the planet: hemispheric tectonics.

"We basically mean upwelling – hot material rising – on one side, and cold material sinking into the mantle on the other side," says Meier. Hemispheric tectonics might be widespread on other tidally locked worlds too, he says. Meier's team has found at least one other planet that could recycle its crust in a similar way. While LHS 3844 b's tectonics would be more lopsided than Earth's, a fragmented, mobile crust broken into plates would at least be a form of plate tectonics, more than can be said for Venus, Mercury or Mars.

Volcanic patterns

We can't yet detect tectonic plates directly on other worlds, but we may still be able to look for them using indirect clues. One possible sign comes in the form of particular patterns of volcanism. This is because a planet's tectonic regime dictates how material moves through its interior, which can have a huge impact on volcanic activity. On Earth, for instance, volcanoes tend to pop up along plate boundaries and only rarely within plates. So, while volcanism itself isn't a smoking gun for tectonics, certain patterns in volcanic activity could be. If LHS 3844 b does have hemispheric tectonics, Meier predicts that one side of the planet would be far more volcanically active than the other.

"[The models] make testable predictions of how volcanism should depend on the day-side temperature and the night-side temperature," says Tim Lichtenberg at the University of Groningen in the Netherlands, who notes it would also be influenced by the planet's size and composition. "The idea is, in the long term, that we can test some fundamental principles of how tectonics works on exoplanets."

Alas, detecting volcanism on exoplanets isn't as easy as pointing a telescope at a rocky world and looking for glowing lava fields. Rocky exoplanets are too small and dim compared with their stars for even JWST to glimpse directly. To learn about what is happening on these worlds, scientists need to use clever workarounds.

Generally speaking, we learn about exoplanets by sifting through the light of their stars. One way to do this is to watch as a planet passes behind its star, causing the star to apparently dim as the glow from the planet's warmth gets blocked out. By isolating that smouldering light, scientists can take the planet's temperature and look for patterns across its surface that may point to volcanic activity.

However, "we are talking about the precision limit of JWST", warns Lichtenberg. "It's very tough to make these measurements." He and other researchers are still attempting it, but in the meantime there are other clues to chase. That's because volcanoes do more than give off heat. They also spew gases into planets' atmospheres – which we might be able to detect.

Our first glimpse of alien volcanic gases could come from the cool "exo-Earth" LP 791-18 d. Björn Benneke at the University of Montreal, Canada, is leading a JWST project to determine whether the planet is wreathed in a CO_2-rich volcanic atmosphere. LP 791-18 d is caught up in a gravitational tug-of-war between its star and a massive neighbouring planet, and the resulting tidal forces should heat LP 791-18 d from the inside out, fuelling intense volcanism, says Benneke.

It is a bit like what is happening to Jupiter's moon Io, which is riddled with hundreds of active volcanoes. "Io is the most volcanically active object in the solar system, and this planet, LP 791-18 d, is in a very similar

"Finding another planet with plate tectonics is a challenge comparable to finding alien life"

situation," he says. Actually detecting this strange world's volcanism would confirm that we can find volcanoes that, on other planets, could be a sign of tectonics.

With the right tools, scientists could eventually start hunting for the chemical fingerprints of specific volcanic gases in the atmospheres of rocky worlds. Work published last year by Colby Ostberg at the University of California, Riverside, and his colleagues investigated whether it would be possible to detect the atmospheric signatures of volcanism on an Earth-like exoplanet using a telescope like the Habitable Worlds Observatory, a proposed successor to JWST that NASA is tentatively aiming to launch in the 2040s.

At one point, the most promising potential signature of volcanism seemed to be sulphur dioxide, which would be bulletproof evidence of recent volcanic eruptions. But the researchers found that its signal would be swamped by that of ozone gas in an atmosphere. However, sulphur dioxide eats away at this gas over time, so fluctuations in ozone levels could point to volcanic activity instead.

It might also be possible to detect volcanic hazes, which would temporarily wipe out other atmospheric features. "If you were to take a series of observations across the span of a year, then you might be able to infer volcanism," says Ostberg.

There is one more way we might be able to get a hint of a planet's tectonic regime: figuring out what it is made of. When JWST ruled out atmospheres on a handful of planets, including the promising LHS 3844 b, "a lot of people were disappointed", says Meier. "But we really need to see this as an opportunity. If these planets don't have an atmosphere, that basically gives us a way of probing the surface directly."

The ground truth

"When life gives you lemons, make lemonade – or when nature gives you airless planets, figure out what you can do with them," says Laura Kreidberg at the Max Planck Institute for Astronomy in Heidelberg, Germany. In this case, we can look at surface rocks. Wherever they are, rocks tell a story. Basalt, a blackish rock that dominates the landscapes of Hawaii and Iceland, forms when lava cools on Earth's surface. Green-hued peridotites make up most of our planet's mantle. And granite – which comprises the bulk of Earth's continents but is practically absent from the rest of the solar system – forms when rock is melted down and recycled over and over, as it is in plate tectonics.

Because of the promise that rocks could tell us the history of distant worlds, researchers are already trying to determine what kind of rock dominates the surfaces of certain airless planets. LHS 3844 b is particularly enticing because it is very hot, but not hot enough to be molten – so its thermal glow is about as easy to spot as is possible for a rocky world. The composition of this glow can tell researchers what kind of rock is present, and even hint at its texture.

Remarkably, this might even let us get a first hint at the contours of LHS 3844 b's landscape. Zieba is now analysing JWST data to figure out whether the planet's surface is smooth, suggesting recent renewal by volcanoes, or made of crumbly, rubble-like regolith. Regolith forms in our solar system when rocky bodies are exposed to space for a long time and pummelled by impacts and the solar wind. If LHS 3844 b's surface is made of regolith, that would be a good indication that its surface is old – a bad sign for plate tectonics.

Studies like this are our first steps into the entirely new field of exoplanet geology, striving to understand the interiors and surfaces of alien rocky worlds. "We have just barely scratched the surface of what there is to learn about rocky planets," says Kreidberg.

But if we are going to understand why Earth is habitable, we will almost certainly need to hunt down plate tectonics elsewhere. It seems to be a crucial part of the habitability equation on our planet and it could be important elsewhere, too. But we can't know for sure until we have more than just our world to examine. "I don't know if we'll ever learn what started tectonics on Earth, just from studying Earth," says Ostberg. "And I think that's why exoplanets are really valuable."

Finding another planet with plate tectonics will be a challenge comparable to finding alien life. It might even be harder, says Benneke, because the signatures of geologic processes are often more ambiguous than those of life. In both cases, we are looking for alien instances of phenomena we can't yet fully explain on Earth. Despite decades of research, neither the origins of life nor the onset of plate tectonics is settled science. Finding the latter might just help us understand the former.

As far as we know, the slow churn of Earth's tectonic plates might be just as special as the tenuous biological veneer growing over them – one of a kind. Or not. Like the search for life, the search for truly Earth-like planets with tectonics will be a long one, a task for future generations of telescopes, and perhaps future generations of researchers. But it's a journey we have finally begun. ▮

SHUTTERSTOCK/VISUALPRODUCTION

The rocks on a planet's surface could tell us what is happening deep underground

Elise Cutts is a science journalist based in Graz, Austria

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An MSF surgical team at Al-Shifa's burn unit in Gaza city cleans the wound of a child after a burn injury.
Photograph © Tetiana Gaviuk/MSF

DR JAVID ABDELMONEIM IS AN MSF DOCTOR RECENTLY RETURNED FROM WORKING IN GAZA.

"At Nasser hospital, we provide trauma surgery and burns care to patients. One Saturday early in my time there, we received hundreds of injured, as well as people who had been killed, following a missile strike.

It was chaos. Our team went to the emergency room. One of the injured was a three-year-old girl. She was breathing and looking at me – so she must be okay, I thought. But as I rolled down her dressing, I found that her entire left thigh was open to the bone.

Seconds later, the doors crashed open. Four to five injured people were brought in, most of them first-aid responders. Among them was a boy who wasn't breathing, so we tried to revive him, but the nurse looked at us and asked: 'Why are we responding to him if he can't breathe? We have to save other lives.' No one had the heart to call it and move on to the next person. He was someone's child. But we had to move on to the next, and then the next, and this continued for another four and a half hours.

In the emergency room, there was blood all over the floor. I had to kneel to see the patients, who were sprawled everywhere because there were no beds left. At the same time, more and more patients were coming in.

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MSFR0048

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The science of exercise

Good for the mind

Working out can benefit the brain in unexpected ways, as **Grace Wade** finds while waiting for a prescription refill

Grace Wade is a health reporter for *New Scientist* based in the US

I HAVE been in a slump the past few weeks, largely due to my ADHD drugs running out. This has made it hard for me to muster up motivation for tasks, including the gym. But I had an epiphany last week once I finally worked out: skimping on exercise was making matters worse. Physical activity may, in fact, be the best way for me to combat my ADHD symptoms while I wait for a prescription refill.

My mind is always a bit quieter after a workout than it was before, in a similar way to when I take my medications. This makes sense. Most ADHD drugs work by raising levels of a brain chemical called noradrenaline, or norepinephrine. This essentially mobilises our body for action by improving focus, memory and impulse control. Levels of it also increase threefold during exercise.

That isn't to say I am ready to ditch my meds. Results are mixed in the studies available on exercise and ADHD. A 2023 review of 106 studies indicated that exercise significantly improves impulse control, attention and the ability to switch between tasks in young children and adolescents with ADHD. However, it had a weak effect on regulating emotions and working memory. The benefits seem to be even less pronounced for adults. In another study last year, 10 minutes of exercise was shown to improve impulse control in 82 adults with the condition, yet had no effect on other ADHD symptoms.

While these findings suggest exercise has only a modest effect on ADHD, they do underscore how working out has other benefits in addition to physical ones. Nowhere is the evidence more robust than when it comes to depression and anxiety.

WESTEND61 GMBH/ALAMY

A 2023 review of nearly 300 trials involving more than 15,800 adults with depression or anxiety found that physical activity was as effective at reducing symptoms of these conditions as talk therapy and medications. The benefit was even stronger when exercise was combined with these treatments.

Other studies have hinted that working out may alleviate symptoms of other mental health conditions, such as bipolar disorder, schizophrenia and obsessive-compulsive disorder.

Physical activity also appears to be protective. A 2018 study of over 1.2 million adults found that those who exercised experienced 43 per cent fewer days of poor mental health, on average, than those who didn't. The link was strongest for team sports, cycling, and aerobic and gym activities. Exercising for 45 minutes three to five times a week also seemed to be the sweet spot. More wasn't always better.

As for me, I am relieved to have discovered a strategy for keeping my ADHD symptoms partly at bay without medications. Even though breaking a sweat is the last thing I want to do when I am overwhelmed or in a slump, I now realise how critical it is to prioritise it. ▮

These articles are posted each week at newscientist.com/maker

The science of exercise appears monthly

Next week
Dear David

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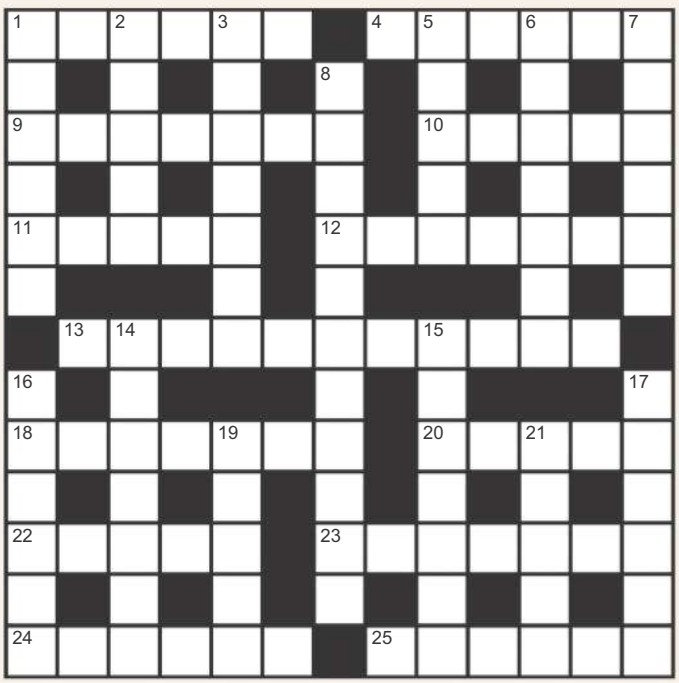
Cryptic crossword #150 *Set by Wingding*



Scribble zone

Answers and our bumper festive cryptic crossword next week.

ACROSS

1 Fix abdominal pain (6)
4 Friend swallowed tongue (6)
9 Idiot cycling with Nobel, informally (4-3)
10 Family member has primary education in French city (5)
11 Dropping bar furniture (5)
12 Master and student kidnapped by sentient computer program (7)
13 Doctor put dangerous animal in front of boxes (11)
18 Perfect gemstone captivates Berners-Lee, for one (7)
20 Circle area showing gas (5)
22 Package from ship left once more without me (5)
23 Politician in bed with overseas extremists – it's rotten stuff (7)
24 Curses the Spanish ryegrass (6)
25 Leaders in Washington approve law regulating unsafe shipping – it's got teeth! (6)

DOWN

1 Rock solid founder of religion runs away (6)
2 Shelter for pig looks incomplete (5)
3 Lower underwear, revealing flower (7)
5 History book leaving out university every year (5)
6 Really good art gallery is plastic (7)
7 Prime number in Spain, once (6)
8 Three conservatives look at development around Michigan timekeeping device (6,5)
14 Italian regent upset one or two? (7)
15 Inability to detect 21 in Samoa after surgery (7)
16 Bird sheltered by hedge mostly made sad sound (6)
17 Sample skin of eczematous sex organs (6)
19 Get by after covering up a skin condition (5)
21 Gas with serious stench (5)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #281
set by Bethan Ackerley

1 The first black hole to be successfully imaged was at the heart of which galaxy?

2 Which is smallest: Dunbar's number, Ferrier's prime or the Hardy-Ramanujan number?

3 Which chemical in turmeric is responsible for its bright yellow colour?

4 In what year did the Tunguska event, the largest impact event in recorded history, take place?

5 What letter denotes the innermost electron shell of an atom?

Answers on page 47

BrainTwister
set by Howard Williams
#49 Squares and cubes

Take two positive whole numbers that are both less than 20. The difference in the squares of these numbers is a perfect cube and the difference in their cubes is a perfect square. (Perfect means that the root of the square or cube is a whole number.)

What are the two numbers?

There is a number between 50 and 100 that you can multiply both these numbers by and get another pair with the same property. What is it?

What property does this number have that makes this work? How can you use this idea to find more of these pairs of numbers?

Solution next week

A killing blow?

Some worms regenerate when cut in half laterally, but what would happen if they were cut in half longitudinally?

Thomas Barker
Cambridge, UK
It seems this depends heavily on which phylum of worm you are bisecting. Most worms in the Annelida phylum can regenerate lost segments to some extent, but many will die if you cut them in half laterally. The tail end of a common earthworm is sometimes able to regenerate in this case, but the head end will never survive. Marine bristleworms, however, can often fully regrow a worm from both pieces if halved laterally.

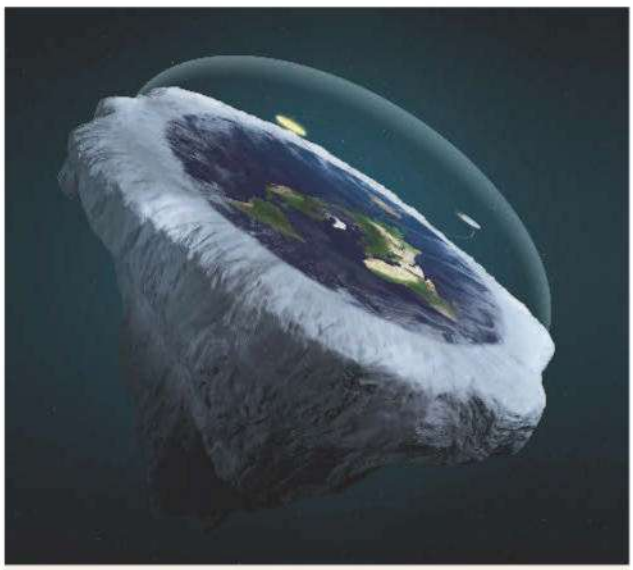
Regardless of which species you pick, though, a longitudinal cut will almost certainly spell doom for an annelid. They have a series of concentric ringed pallial blood vessels running down their bodies. A cut down the length of the worm will inevitably sever all of these. Even if the worm somehow survives this, to recover it would then have to regrow half of its body after losing much blood and with a non-functional digestive system.

"A 2011 article reported a flatworm growing two identical heads after its original head was cut in half down the middle"

The story is very different if you have a planarian flatworm of the Platyhelminthes phylum under the scalpel. These are already something of a *New Scientist* favourite thanks to their neoblasts, clumps of adult stem cells that give them incredible regenerative abilities. One flatworm in an 1898 study was able to regrow from just 1 per cent of its original body. Meanwhile, a 2011 *New Scientist* article reported another flatworm growing two identical heads after its original was cut in half down the middle. Surviving a longitudinal cut is well within the capabilities of these worms.

Kevin Lumney
Sunbury, Ohio, US
Among bilateral animals, and worms particularly, planaria are well known for their proficiency at regenerating missing portions of their bodies. My daughter, for a middle school science project, explored the limits of this phenomenon when adults of such worms were sectioned laterally (dividing the head from the tail) at varying distances from the middle of the body.

She did find there was a point at which the smaller portion of the worm resulting from her cut was incapable of regenerating the missing part of its body (though of course the larger portion easily regenerated its lost part). If by a "longitudinal cut" the questioner means sectioning a planarian (for example) worm's body lengthwise at varying distances from its sagittal plane (the plane dividing it into equivalent right and left mirror-image halves), I would be willing to bet a similar limit exists, where a portion is just too small to entirely regenerate.



OSCAR COLLICA/ALAMY

What might gravity be like on an imagined disc-like Earth (minus the giant space turtle)?

This week's new questions

On the level **If Earth was flat, how would gravity manifest?** ***Terence Partridge****, San Jose, California, US*

Those who remain **Why did crocodiles, turtles, lizards and birds survive the Cretaceous-Palaeogene extinction event, but non-avian dinosaurs didn't?** ***Fred Zemke****, Grover Beach, California, US*

Jet stream

What would happen if a black hole jet hit the sun or Earth?

Herman D'Hondt
Sydney, Australia
As in real estate, it is all about location, location, location.

The effects of a jet produced by an active black hole depend very much on how close we are to the black hole and its size. The larger the black hole, the larger the jet. Are we talking about a stellar black hole or a supermassive one? In all cases, if it is far enough away, we need telescopes to notice it. Close enough, and the entire solar system could be fried to a crisp.

Consider a somewhat less extreme example: rotating neutron stars, otherwise known as pulsars. These stars contain the mass of several suns in an object the size of a city. Most of them rotate several times per second or faster. Like black holes, they can emit beams of radiation as well as jets of particles from their poles. Those particles travel at around half the speed of light.

Some of those jets are aimed at Earth. That is how pulsars were discovered, when in 1967 Jocelyn Bell noticed extremely regular radio pulses coming from a point in space. After eliminating the idea that the pulses were an alien signal (jokingly dubbed LGM-1, for "little green men"), it was found that they happened when the beam of a pulsar sweeps over Earth.

Apart from radiation, these stars can also emit jets of nuclear particles, and even anti-particles. Unlike radiation, particle beams are affected by the magnetic fields in interstellar space. This means they defocus more rapidly than beams of radio waves. We have detected such a beam from at least one pulsar, but its beam isn't aimed at us, and it is much too far away to affect us.

Because we are here, we can confidently state that Earth has never been close enough to a pulsar to be harmed by its jets – or by the supernova explosion that created the star – so it is unlikely to happen in the foreseeable future.

The chances of our world being in the beam path of a nearby supermassive black hole

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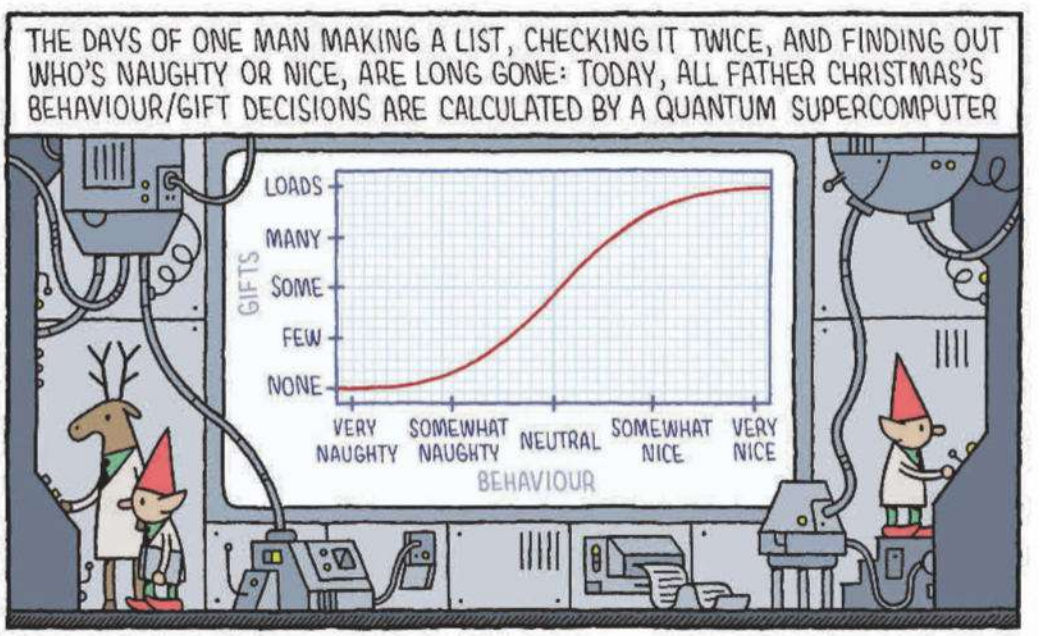


are far smaller still, as there are no galaxies with active black holes nearby.

Play on

Presumably music is an essential part of human evolution or it wouldn't be there, but why? (continued)

Richard Widdess
Cambridge, UK
Music can't be dismissed as an incidental byproduct of other factors: it has potentially had huge evolutionary significance. Music is of many kinds, fulfils many functions and involves various cognitive capacities, so its evolutionary significance is likely to be complex and varied.

To give one example, humans have a remarkable capacity that is rare in the animal kingdom: the ability to predict a regular beat and entrain our bodies to it. This allows us to engage collectively with other humans in complex musical and dance performances, leading to alignment of emotional states, which in turn may have had a very significant impact on the evolution of human societies.

"Early humans may have warded off predators at night through their loud choral singing, a clear survival advantage"

Recent research has argued that such abilities may have enabled early humans to ward off predators at night through loud choral singing, a clear survival advantage, and that participatory group singing is particularly well equipped to engender processes fundamental to human social evolution, including social bonding, group identity, religious expression and ritual performance. Human society might not have evolved, or survived, without music.

Richard Ellam
Bristol, UK
The idea, raised in a previous answer, that a 40,000-year-old bone flute suggests music may have preceded language is probably mistaken. I dabble in playing and making woodwind instruments. My experience suggests this ancient flute is evidence its makers spoke a complex and sophisticated language, maybe one that was as subtle as any of the thousands that are spoken today.

Making and playing a bone flute isn't a trivial exercise. You need to know more or less where to put the holes, you need to make the tools to make the holes, and you need someone to teach you how to do all of these things or (if you're the inventor) someone to teach. It is hard to see how all this could be conveyed successfully unless the makers could talk to each other as well as us.

It may well be that language and music developed together, but I am pretty sure that whoever made that little flute had all the language skills they needed to talk about making it, and how they were much better at flute-making than that idiot in the next cave! ▮

Answers

Quick quiz #281 *Answers*

1 Messier 87
2 Dunbar's number (150)
3 Curcumin
4 1908
5 K

Quick crossword #172 *Answers*

ACROSS 1 Jaundice, **5** Acarid, **10** Leucoma, **11** Aerobic, **12** Ounce, **13** Suspended, **14** Fairy penguin, **18** Bathyspheres, **21** Countdown, **23** Servo, **24** Stimuli, **25** Niobium, **26** Areola, **27** Hydrogen

DOWN 1/6 Joliot-Curie, **2** U-turns, **3** Dromedary, **4** Claustrophobia, **7** Rubidium, **8** Decoding, **9** False pregnancy, **15** Niels Bohr, **16** Abscissa, **17** Struvite, **19** Drying, **20** Zoom in, **22** Trurl

#48 Rock, paper, scissors *Solution*

Since each play results in one player's score increasing and the other decreasing (or staying the same), the scores will always be N and -N, for some value of N, so the total after any number of plays will be 0. For the modified game, a player should pick paper twice as often as scissors (since it is twice as good against rock) and scissors equally as often as rock. All probabilities must add to one, so each time we should choose rock with probability 1/4, paper with probability 1/2 and scissors with probability 1/4. If we award 3 and -3 points when rock blunts scissors, the probabilities for paper, rock and scissors become 3/5, 1/5, 1/5. If we award N and -N points, the ratio must be N : 1 : 1.

A biblical approach

Praise be, there is a new book from psychologist-turned-YouTuber Jordan Peterson. *We Who Wrestle With God* is about how ancient myths and legends, while perhaps not literally true, contain valuable and even universal lessons about life and humanity.

Feedback was nodding along to this. Anthropologists will tell you there's a lot to be gleaned from the study of myths. You can get a sense of how past societies thought about the relationships between ordinary people and elites, or their views on humanity's place in the natural world.

But then we got to the final page of the introduction and the penny – which had somehow remained elevated – dropped. This isn't a global survey. It is solely about stories from the Bible, and almost entirely from Genesis and Exodus, because the Bible is "the story on which Western civilisation is predicated" and "the foundation of the West, plain and simple".

Feedback's grasp of intellectual history is admittedly a little hazy, but we are pretty sure Western societies and modern science, while shaped by Christianity, were also influenced by ideas from the ancient Greeks, the Roman Empire, the Norse, the Arabic scholars that laid the foundations for the scientific revolution, and more.

But we aren't going to pretend we are expert in Biblical exegesis. We are happy to leave the theological critique to Rowan Williams, former Archbishop of Canterbury, who says Peterson "relies a lot on rather dated Christian commentaries" and has an "insistent contempt for nuance and disagreement".

Instead, we will unpack one little section, where Peterson tries to link his ideas to human biology – something we do know a bit about.

The problem with Eve

Chapter 2 is about Adam and Eve being thrown out of the Garden of Eden after Eve, tempted by a serpent, eats a forbidden fruit and talks Adam into doing the same.

Peterson says this reflects fundamental flaws in the minds of men and women. "The temptation that eternally confronts the woman," he writes, "is the idea that maternal benevolence can be pridefully extended to the entire world, to even the most poisonous of snakes... to use her compassion, however ill-placed and false, to claim unearned moral virtue and ability."

Meanwhile, men have "a corresponding and equally deadly sin", which is the belief that they can "incorporate, master, name and subdue, and put into proper order anything that you bring before me" – no matter how "overreaching" or "preposterous".

It is the role of women to be compassionate, drawing men's attention to those who are suffering, while men must exercise their "emergent authority" and make judgements about who deserves help.

Given this book purports to reveal absolute truths about human nature, Feedback enjoyed the lack of self-reflexiveness in that line about the dangers of "overreaching".

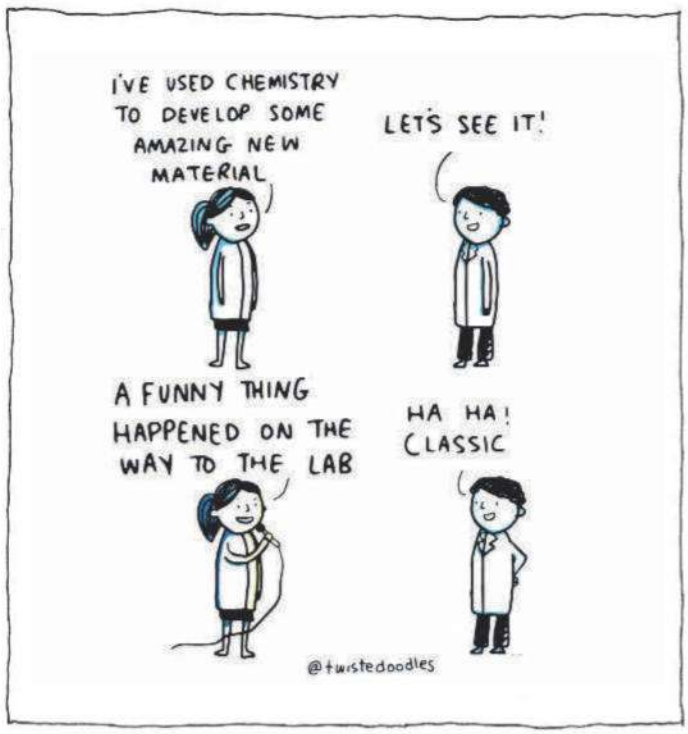
Now, you might expect Peterson, a psychologist, to offer psychological evidence for these differences between men and women. You would be wrong. But he does try to link it to the biology of childbirth. Labour, he explains, is painful and dangerous because human babies have evolved bigger brains, which must fit through a narrow birth canal that cannot get any wider or "women would have trouble running".

This triggered the firing of a neuron in Feedback's overloaded brain. Peterson is restating a hypothesis called the "obstetrical dilemma", set out in 1960.

Today, it is one of the most contested notions in anthropology: its underlying assumptions have all proved untrue or questionable. A 2018 study was bluntly titled "There is no 'obstetrical dilemma'". A 2021 riposte said that (deep breath) "it is unwarranted to reject the obstetrical dilemma hypothesis entirely because several of its fundamental assumptions have not been successfully discounted".

Feedback isn't wise enough to resolve this knotty dispute. But at least, unlike Peterson, we realise that. He goes on to say pregnant and nursing women manifest "increased dependency" and therefore cannot compete with men for status, and at this point we exercised our emergent authority and stopped reading.

Twisteddoodles *for New Scientist*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A FUNNY THING HAPPENED ON THE WAY TO THE LAB
HA HA! CLASSIC
@twistedoodles

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Word of the year

Feedback enjoys the annual ritual of dictionaries announcing their word of the year, which tells us something about shifting mores. We were especially pleased to learn of the existence of the Macquarie Dictionary, the national dictionary of Australia, and its decision that the word of 2024 is "enshittification".

This excellent word was coined by writer Cory Doctorow to describe how companies gradually make their services worse as they squeeze more profits out of their customers. He was referring to companies like Google, whose search results are riddled with adverts and untrustworthy AI-written summaries, and Facebook, whose newsfeed is so full of memes and adverts that you can barely see anything from your friends or family.

Feedback has been using the word ever since we read Doctorow's initial essay, and we are delighted to see it find a wider audience.

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